Examining the Respiratory Compensation Point with Automated Methods in Recreational Runners Training for a Marathon

A Thesis
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE

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MAY 2019

Acknowledgements

I would like to acknowledge my committee member Chris Lundstrom, the instructor of the marathon training class at the University of Minnesota, for his support throughout this endeavor. From the initial opportunity to use data from the marathon class during a directed study and throughout all aspects of this process, I am incredibly grateful.

My additional committee members Dr. Li Li Ji, Dr. Eric Snyder, and Dr. Mindy Kurzer. Thank you for your support during this long journey.

Dr. Robert DelMas for the many hours and visits to learn, for the first time, the necessary statistics to complete this thesis. You most certainly put in extra time of your own and I am incredibly grateful.

Dr. Panteleimon Ekkekakis from Iowa State University for providing me with a free academic copy of WinBreak 3.7, the automated software I used for detecting the respiratory compensation point. The final version of this research would not be the same without your guidance regarding the use of WinBreak for my study design.

Morgan Betker, Emma Lee, Nick Foreman, and the many other unnamed graduate assistants and undergraduate students who helped collect data at pre and post marathon testing sessions: data collection would not be possible without so many hands.

To Ellen Hawley and to my parents, Jon and Lynne Hesse, for your support throughout all aspects of my Master's degree.

Abstract

Background: The respiratory compensation point (RC) approximates the lowest intensity of unsustainably difficult exercise, making it an important measure for endurance athletes. Thus, accurate determination of RC is important to athletes. There are many methods to determine RC, but few large studies to date have compared multiple automated methods. Previous studies have shown that rates of detection of RC (i.e. determinate cases) vary. The purpose of this study was to compare four common methods used to detect RC: Jones-Molitoris (JM), Orr, Beaver's V-slope (Beaver), and the Dmax method. **Methods:** Recreationally active college students (n = 131, 45 males, 86 females) completed 2-mile time trials and graded exercise tests both before and after training for a marathon. The four methods were used to detect RC (as a % of VO_{2max}) from the V_E vs. VCO_2 slope. The number of determinate RC cases were recorded for each method at pre and at post. Determinate counts of RC were expressed as a percentage, were compared pre to post with Fisher's exact tests, and were simulated with bootstrap resampling. Average differences between methods were compare using a linear mixed effects model (LMEM) with data from participants who displayed RC at both pre and post testing for at least one of the four methods. Comparisons between methods and with 2-mile performance were also compared by correlations and with limits of agreement (LOA) plots. **Results:** The order of determinate rates from highest to lowest was JM, Dmax, Orr, and Beaver. Fisher's exact tests produced odds ratios significantly higher than 1 for all but Beaver. Histograms of bootstrap resampling showed large overlap for all but the Beaver method. LMEM analysis showed that JM predicted significantly higher RC than Beaver and Dmax, but not Orr. All methods were significantly correlated with one another at both timepoints. LOA were wide. **Conclusions:** Beaver detects RC more infrequently than other methods. It is unknown if the higher $\%VO_{2max}$ at RC predicted by JM is an overestimate. Although all methods highly and significantly correlate to one another, they have wide LOA. A better automated method may combine the results of several methods.

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Chapter 1: Introduction

Ventilatory thresholds (VT) are one category of physiological markers used to assess endurance performance and cardiovascular function. Numerous studies have found that VT, or the closely associated variable, lactate threshold, (LT), are more highly correlated with prolonged endurance performance than VO_{2max} and other markers (Faude, Kindermann, & Meyer, 2009; Jacobs, 1986). In addition, VT can be useful for measuring cardiovascular health (Wasserman & McIlroy, 1964), for prescribing exercise, and for evaluating daily life activity (Tamai et al., 1993). When used to prescribe exercise, basing intensity relative to a threshold is superior to a percentage of VO_{2max} or max heart rate because thresholds are more individualized (Hall, Ekkekakis, & Petruzzello, 2002; Tim Meyer, Gabriel, & Kindermann, 1999). Specifically, prescribing exercise at intensities above the second ventilatory threshold (VT_2) or the second lactate threshold (LT_2) could result in premature fatigue, and exercise too far below the same threshold may fail to elicit the desired adaptations (Davis, 1985a; Gallagher, Willems, Lewis, & Myers, 2014). When compared to measuring LT, VT poses an advantage over LT as an assessment tool because lactate threshold tests require more invasive measuring techniques involving blood samples from finger or earlobe pricks or from intravenous catheters. Measuring VT requires access to a metabolic gas analysis system, and while this is not readily available to the general public, it is standard equipment in most exercise physiology labs.

Endurance athletes in particular may reap the greatest benefits from an accurate measurement of VT_2, also known as the respiratory compensation point for metabolic acidosis (RC) (Wasserman, Whipp, Koyl, & Beaver, 1973). The intensity at RC may equal or closely approximates many other "thresholds" such as the anaerobic/second lactate threshold (LT_2), the maximal lactate steady state (MLSS), or critical power/velocity (CP or CV) (Ahmaidi et al., 1993; Broxterman, Craig, & Richardson, 2018; A. D. Keir, Pogliaghi, & Murias, 2018; D. A. Keir et al., 2015; K. Meyer et al., 1996; Wasserman, 1999; Wyatt, 1999). As such, RC can predict an athlete's upper sustainable limit of exercise intensity. Notably, there is contentious debate surrounding the use of the RC in place of CP/CV or MLSS (Broxterman et al., 2018; A. D. Keir et al., 2018). Although most authors cannot find differences on average between RC and

CP/CV or MLSS, a precise mechanistic link between such values is still unknown and RC has been criticized for its high intrasubject variability and lack of correlation with CP/CV or MLSS (Broxterman et al., 2018). Nevertheless, RC may be useful when predicting race performance and it is an important intensity for endurance training. Training at this intensity even bears the name "threshold training", demonstrating the importance of this intensity to endurance programs (Daniels, 2013; Freeman, 2017; Jenssen, 2001; Pierce, Murr, & Moss, 2007; Reuter, 2012). Although both VT_1 and RC are important to endurance athletes, precise knowledge of RC is likely more useful to endurance athletes than VT_1 because the RC is often more event specific. As such, athletes and coaches would have an interest in more accurate information regarding a key performance indicator and training intensity.

Despite the potential benefits, precise determination of VTs remains subject to debate. There are numerous calculation methods for both VT_1 and RC, and most studies compare only VT_1 calculation techniques. To date, only two studies have compared multiple automated RC methods. Santos and Giannella-Neto (2004) found no significant differences between the first derivative maxima of V_E/VCO_2 vs. VO_2 plots, second derivative zero-crossing points for V_E vs. VCO_2 plots, nor breakpoint regressions of end tidal carbon dioxide ($P_{ET}CO_2$) vs. time plots. Zhou and Weston (1997, p. 148) used Orr's method on plots of V_E, VCO_2, $P_{ET}CO_2$, V_E/VO_2, and V_E/VCO_2 vs. VO_2 and took the average of "the three of the most consistent values of exercise time." These authors did not specify which of the five plots represented the "most consistent values". Nevertheless, the $\%VO_{2max}$ at RC did not significantly differ from RC determined visually, from 4.0 mmol/L lactate, or from D-max applied to lactate measures at initial testing. At retesting four weeks later, however, the $\%VO_{2max}$ of the automated RC was significantly higher than 4.0 mmol/L lactate and D-max lactate, but significantly less than visual RC. Importantly, 4.0 mmol/L of blood lactate is a good estimate of the upper sustainable limit of exercise intensity for many individuals (Heck et al., 1985). However, results from other studies show that the concentration of lactate an individual can sustain for long periods of time can range from 1.5 – 6.3 mmol/L (Beneke, 1995, 2003; Dekerle, Baron, Dupont, Vanvelcenaher, & Pelayo, 2003; Pedersen, Sj, & Juel, 2001). Therefore, it is unknown if the automated RC in the study by Zhou and Weston (1997) was an

overestimate of the participants' upper sustainable limit of exercise intensity or if participants could tolerate greater than 4.0 mmol/L lactate.

Given that only two studies comparing automated testing have been published to date, many automated RC methods have yet to be compared, such as Dmax, cumulated sums (CUSUM), and 2nd derivative inflexion points. In addition, finding an automated method that is consistently superior to visual detection methods may reveal whether or not RC can truly represent the same exercise intensity as CP/CV or MLSS.

Therefore, the RC detection method with the strongest relationship with endurance performance is currently unknown. In addition, it is also unknown if any automatic methods are superior in reducing or eliminating indeterminate cases. In order to assess the predictive power of each method, all methods must first be compared against one another to determine if they produce similar results. Similar to how Santos and Giannella-Neto (2004) found no differences among automated methods, we hypothesize that the Jones and Molitoris, Orr, and Beaver's V-slope breakpoint regressions, as well as the Dmax method, will not result in significant differences in the $\%VO_{2max}$ at RC when applied to the V_E vs. VCO_2 plot. We also hypothesize that some methods will have different rates of detection.

Chapter 2: Review of the Literature

2.1 Ventilatory Thresholds

The two ventilatory thresholds (VT) are disproportionate increases in minute ventilation (V_E) or VCO_2 above VO_2. However, both VTs corresponds to more general "thresholds" of exercise intensity that encompasses changes in ventilation and blood lactate concentration. Such changes in often coincide closely (Ahmaidi et al., 1993; D. A. Keir et al., 2015; Wyatt, 1999), but do not necessarily occur simultaneously (K. Meyer et al., 1996; Powers, Dodd, & Garner, 1984). Any causal link between them is partially related to the bicarbonate buffering system (T Meyer, Faude, Scharhag, Urhausen, & Kindermann, 2004; Péronnet et al., 2007), metaboreceptors, core temperature, mechanical receptors in the muscles, and potassium (T. Meyer, Lucia, Earnest, & Kindermann, 2005). To date, the extent to which each factor determines the link between ventilatory and lactate measures is still unknown, and as such the debate on this issue has been hotly contested (Bosquet, Léger, & Legros, 2002; Brooks, 1985a, 1985b; Broxterman et al., 2018; Davis, 1985a, 1985b; A. D. Keir et al., 2018; Leo, Sabapathy, Simmonds, & Cross, 2017; McLellan, 1987).

To minimize confusion, it is important to discuss the nomenclature surrounding this topic. First, scientists studying these thresholds may use nomenclature to describe each threshold generally (e.g. aerobic and anaerobic thresholds) or refer specifically to the lactate or ventilatory nature of each threshold. In addition, the same terminology has been used to refer to either threshold. Finally, there is no consensus on what vocabulary to use, resulting in another layer of confusion (Binder et al., 2008). Thus, it is important to review the background physiology and research history occurring at both thresholds in order to clearly understand and differentiate the relevant terminology. For a more detailed account of this history, the reader is encouraged to refer to the review by Ferguson et al. (2018).

2.2 The First Threshold

At lower levels of intensity, or approximately 50% VO_{2max} or below, there is a linear increase in oxygen consumption (VO_2) as well as equivalent increases in both

carbon dioxide (CO_2) output and minute ventilation (V_E). At these lighter workloads, there is no significant increase above baseline blood lactate concentrations. However, after further increases in exercise intensity, baseline lactate concentrations rise, and there is a disproportionate change in V_E and compared to VO_2 (Powers & Beadle, 1985). The initial and predominating name for this first threshold was the “anaerobic threshold” (Wasserman & McIlroy, 1964). At the time, it was thought that at this intensity the muscles lacked sufficient oxygen for energy production and thus began anaerobic metabolism, as observed from the production of lactate (Wasserman & McIlroy, 1964). However, subsequent reviews show more support for an imbalance between lactate removal and production (Brooks, 1985a; Davis, 1985a; Ferguson et al., 2018; Mahon & Cheatham, 2002), α and β-adrenergic stimulated release, time-dependent release from skeletal muscle, and contraction independent glycolysis (Brooks, 1998), rather than muscle hypoxia.

The increase in ventilation that coincides with the increase in lactate above baseline occurs in order to buffer lactic acid (Davis, 1985a; T. Meyer et al., 2005; Powers & Beadle, 1985; Wyatt, 1999). Briefly, lactic acid produced by the muscles quickly and nearly completely dissociates into a lactate anion and a proton (H^+) because of its relatively low pKa value compared to blood pH. As a result, a sodium bicarbonate anion accepts a proton to form carbonic acid (Wasserman, Van Kessel, & Burton, 1967). Carbonic anhydrase catalyzes the dissociation of sodium bicarbonate into water and carbon dioxide. Peripheral carotid bodies and central chemoreceptors then sense this increased pCO_2 and stimulate increased ventilation to lower pCO_2 via exhalation (Wasserman, Whipp, Koyal, & Cleary, 1975). Thus, the increase in V_E is primarily from greater expired VCO_2.

Given the changes in lactate concentration and ventilation, the terms “lactate threshold” (LT) and “ventilatory threshold” (VT) also mark this first threshold. In addition, later authors have used the term “*ae*robic threshold”, as opposed to "*an*aerobic threshold" for the first threshold because aerobic metabolism still predominates (Kindermann, Simon, & Keul, 1979; T. Meyer et al., 2005). Although it is now known that rise of lactate levels above baseline at this threshold is due to an imbalance of lactate

removal and production instead of an anaerobic environment, it can create confusion when terms with opposing prefixes demarcate the same threshold.

2.3 The Second Threshold

As exercise intensity increases further, one eventually reaches the second threshold, which again coincides with changes in lactate concentration and in ventilation. The rating of perceived exertion (RPE) of this intensity is approximately 13–16 on the Borg 6 – 20 RPE scale (Bergstrom et al., 2012; Green, Crews, Bosak, & Peveler, 2003; Harnish, Swensen, & Pate, 2001; Mendes et al., 2013; Swensen, Harnish, Beitman, & Keller, 1999). This intensity is verbally described as "comfortably hard" (Daniels, 2013), and corresponds to the descriptors of "somewhat hard", or "hard" according to the Borg 6 – 20 scale (Borg, 1998).

After crossing this threshold, blood lactate concentration rises rapidly, respiration increases dramatically, and muscles begin to fatigue, together resulting in increased effort despite the same workload. This unsustainable effort eventually requires slowing down or stopping exercise. This second threshold, like the first, is also referred to as a lactate threshold. However, it is not uncommon to read literature citing the "onset of blood lactate accumulation" (OBLA). Often, the OBLA refers to a specific concentration of 4 mmol/L of blood lactate (Sjödin & Jacobs, 1981). Though a good estimate for most individuals, the "maximal lactate stead state" (MLSS) or the "individual anaerobic threshold" (IAT) accounts for individual variation in this second threshold with reference to lactate (Ahmaidi et al., 1993; Beneke, 1995; Stegmann, Kindermann, & Schnabel, 1981). This threshold approximates the highest intensity at which one can sustain intense exercise for extended periods of time without fatigue. As such, endurance athletes and coaches have an interest in raising this threshold so athletes may exercise at a higher percentage of their maximum pace and thus outperform their competitors (Daniels, 2013; Freeman, 2017; Jenssen, 2001; Joyner & Coyle, 2008; Pierce et al., 2007; Reuter, 2012). Marathon or other endurance training by recreational distance runners results in thresholds at high percentages of VO_{2max} or faster speeds at each threshold (Ferrauti, Bergermann, & Fernandez-Fernandez, 2010; Keith, Jacobs, & McLellan, 1992; Vesterinen et al., 2013). In addition, running specifically at the velocity associated with

lactate threshold can dramatically improve this speed and the percentage of VO_{2max} of this intensity, even without changes in VO_{2max} (Coyle, 2007).

The increase in ventilation from surpassing the second threshold occurs to buffer metabolic acidosis from accumulating H^+, although several other aspects are partially responsible for the increased ventilation (T Meyer et al., 2004; T. Meyer et al., 2005). This causes a rise in V_E/VCO_2 and V_E/VO_2 relative to VO_2. Accordingly, this is referred to as a ventilatory threshold. A prominent name for the second ventilatory threshold is the "respiratory compensation point for metabolic acidosis" (RC or RCP) (Wasserman et al., 1973).

To add additional complication to this terminology, not all authors are careful to specify the first or second threshold when they use the terms lactate (LT_1 or LT_2) or ventilatory threshold (VT_1 or VT_2). Also, several authors (Kindermann et al., 1979; T. Meyer et al., 2005; Stegmann & Kindermann, 1982) and most coaches choose to refer to the second threshold as the "anaerobic threshold" or the "lactate threshold" (Daniels, 2013; Freeman, 2017; Pierce et al., 2007; Reuter, 2012). This could confuse readers accustomed to Wasserman and McIlroy's original definition of the first threshold as the "anaerobic threshold" (Wasserman & McIlroy, 1964). For a more complete list of terms related to either threshold, please see Binder et al. (2008). Finally, as McLellan (1987) argues, some authors (Hagberg, Coyle, Miller, Martin, & Brooke, 1982; Hughes, Turner, & Brooks, 1982) may have initially misattributed VT_1 for VT_2, thereby further complicating this topic.

2.4 Lack of a Gold Standard for Measuring Ventilatory Thresholds

While VT can be used as a non-invasive procedure for estimating endurance performance and cardiovascular health, it is important to note that despite this advantage, there is no "gold standard" for measuring either VT_1 or VT_2. Given that, determining these inflection points with precision is subject to debate. In early and more recent studies, trained researchers used graphical ventilation data to determine VT manually (Ahmaidi et al., 1993; Beaver, Wasserman, & Whipp, 1986; Hughes et al., 1982; Myers et al., 2010; Posner, Gorman, Klein, & Cline, 1987; Rhodes & McKenzie, 1984; Simonton, Higginbotham, & Cobb, 1988; Wasserman & McIlroy, 1964; Wasserman et

al., 1973). However, many researchers have noted that this method lacks objectivity compared to mathematical models (Beaver et al., 1986; Cheng et al., 1992; Coyle et al., 1983; Fabre, Balestreri, Pellegrini, & Schena, 2010; Gallagher et al., 2014; Gregg, Wyatt, & Kilgore, 2010; Janeba, Yaeger, White, & Stavrianeas, 2010; M Kara, Gokbel, & Bediz, 1999; T. Meyer et al., 2005; Myers et al., 2010; Orr, Green, Hughson, & Bennett, 1982). Some of those models include breakpoint algorithms (Jones & Molitoris, 1984), a "brute force" model (Orr et al., 1982), linear-quadratic regressions (Crescêncio et al., 2003), "V-slope" (Beaver et al., 1986), "modified V-slope" (Gaskill et al., 2001), "simplified V-slope" (Sue, Wasserman, Moricca, & Casaburi, 1988), "Dmax" (Cheng et al., 1992), modified D-max protocols (Bishop, Jenkins, & Mackinnon, 1998; Fell, 2008), cumulative sums (CUSUM) (Bischoff & Duffin, 1995; Duffin, 1994; M Kara et al., 1999; Smith & O'Donnell, 1984), and nonparametric polynomial regression analysis (Santos & Giannella-Neto, 2004; Sherrill, Anderson, & Swanson, 1990; Wade et al., 1988). These algorithms hopefully resolve issues such as such as indeterminate cases, low agreement between reviewers, low agreement between visual and computerized methods, and low agreement between results gleaned from plots with different respiratory variables (Ekkekakis, Lind, Hall, & Petruzzello, 2008)

In this paper, we will focus on determination of RC using 3 different breakpoint methods, the Jones-Molitoris (JM), Orr, and Beaver's V-slope methods (Beaver), as well as the Dmax method, all with the V_E vs. VCO_2 relationship.

2.5 Breakpoints Formulas for Ventilatory Equivalents and Related Methods

When using ventilatory equivalents, VT_1 occurs when V_E/VO_2 shows a non-linear increase while V_E/VCO_2 stays constant. In this case, V_E/VCO_2 is constant because increased CO_2 production from buffered lactate is the gas that contributes to the excess ventilation (Wasserman, 1987). In addition, the end-tidal oxygen ($P_{ET}O_2$) will increase without a decrease in the end-tidal carbon dioxide ($P_{ET}CO_2$) (Simonton et al., 1988; Skinner & Mclellan, 1980; Wasserman et al., 1973). When determining RC, researchers will look for the point at which both V_E/VO_2 and V_E/VCO_2 show a disproportionate rise compared to VO_2 (McLellan, 1987). Other authors have also used V_E, V_E/VO_2, and V_E/VCO_2 plotted against workload as a way to determine both thresholds (Ahmaidi et al.,

1993). Ahmaidi has noted that V_E increases at both VT_1 and VT_2, that V_E/VO_2 increases disproportionally at both thresholds, and that V_E/VCO_2 decreases before VT_1 and remains constant until rising at VT_2. Finally, one can also measure the beginning of a systematic decrease $P_{ET}CO_2$ at RC (Simonton et al., 1988; Skinner & Mclellan, 1980).

In all cases, both VT_1 and RC can be determined visually or with computerized breakpoint algorithms. Common breakpoint algorithms find the smallest sum of squares for two regression lines (Jones & Molitoris, 1984) (JM) or the least pooled residual sum of squares for two regression lines (Orr et al., 1982) (Orr) to objectively find these breakpoints. A final common technique finds RC by a preselected 15% change in slope for the V_E vs. VCO_2 plot (Beaver et al., 1986). If a 15% change in slope is found, Beaver's V-slope method (Beaver) fits two regression lines against a single regression line such that it maximizes the ratio of the distance of the intersection point of the two regression lines to the single regression line. This is normally applied to the VO_2 vs. VCO_2 plot to find VT_1. In this study, we will use the maximized ratio portion of Beaver's method with the V_E vs. VCO_2 relationship.

2.6 The D-max Method

Although the above methods can help find ventilatory thresholds objectively and more often compared to visual detection, they sometimes fail to find all cases of each threshold (Beaver et al., 1986; Ekkekakis et al., 2008; Gallagher et al., 2014; Orr et al., 1982; Sherrill et al., 1990). Non-detection may occur because the ventilatory response may trail metabolic responses in patients with airway obstructions, obesity, or chemoreceptor insensitivity (Beaver et al., 1986). Non-detection can also occur because of entrainment, such as during cross country skiing (Fabre et al., 2012). Entrainment is synchronized breathing to locomotion and it is typically more pronounced with greater upper limb involvement (Bramble & Carrier, 1983). Entrainment can interfere with detection because it can also override chemoreceptor of ventilation (Fabre et al., 2012).

To resolve the issue, Cheng et al. (1992) developed the Dmax method (Dmax) because it finds a threshold by definition. The Dmax locates a threshold by making a third order curvilinear regression equation, usually with VCO_2 or lactate concentrations plotted against VO_2 or workload (Cheng et al., 1992; Newell, McMillan, Grant, &

McCabe, 2006). A straight line is then drawn between the two endpoints of the data and a computer algorithm finds the point on that line with the longest distance to the curved line. Their intersection is defined as the threshold. By doing so, the Dmax method ignores irregular ventilation patterns that can prevent detection by other methods (Cheng et al., 1992). The Dmax method coincides more with VT_2 than VT_1 (Zhou & Weston, 1997), but it can be adapted for use with the V-slope method to determine VT_1 (Epistemic Mindworks, 2003).

Despite finding a threshold by definition, it should be noted that the Dmax method relies on "subjective decisions made in producing the data" (Janeba et al., 2010). It has been demonstrated that using the Dmax to assess lactate thresholds can yield different results when selecting the first (Bishop et al., 1998) and last (Janeba et al., 2010) data point and that it may be dependent on the initial workload (Janeba et al., 2010; Zhou & Weston, 1997). This would suggest that when using the Dmax method to find RC, it is important to ensure subjects reached their VO_{2max} and do not stop beforehand. However, Janeba et al. (2010) wrote that since there is no physiological connection between the LT_2 and maximal lactate concentration, the inclusion of the maximal lactate concentration is unjustified. Hence, these authors argue that there is undue reliance upon the maximal lactate concentration to determine LT_2 using the Dmax. Therefore, there may also be undo emphasis on attaining a subject's true VO_{2max}. That aside, lactate threshold tests usually have a smaller number of data points with which to produce a lactate curve because one sample is typically taken at the end of 1- or 2-minute stages, thus placing their data points farther apart. In contrast, ventilatory tests have abundant data points that are often then averaged. Therefore, if subjects nearly attained but did not push themselves to a true maximum effort, determination of RC by the Dmax may be less skewed because there will likely still be other data points relatively closer to the VO_{2max}. Thus, LT_2 measured by the Dmax may be more vulnerable to the first and final data points compared with ventilatory data.

2.7 Cumulative Sums (CUSUM)

Cumulative sum control charts (CUSUM) are often used in quality control settings to determine changes from a mean. CUSUM charts show the difference between

the average value and the subsequent value, allowing one to see if the subsequent values are drifting over time. Plotting V_E, V_E/VO_2, and VE/VCO2 against time allows one to observe deviations from a constant value or disproportionate increases. This can be determined both visually (Bischoff & Duffin, 1995; Duffin, 1994; M Kara et al., 1999) or mathematically (Smith & O'Donnell, 1984).

Until reaching the first threshold, V_E/VO_2 should show only random variation about a constant value, after which it will rise because of non-metabolic CO_2 from lactic acid buffering (Smith & O'Donnell, 1984). Meanwhile, the V_E/VCO_2 will remain constant until the second threshold, after which it will rise from respiratory compensation for metabolic acidosis.

Other authors have visually determined a breakpoint in CUSUM charts that plot V_E vs. time (Bischoff & Duffin, 1995; Duffin, 1994) or VCO_2 vs. time (M Kara et al., 1999). Either of those two plots will show steady increase in both V_E and VCO_2 until reaching VT_1, at which point the slope will increase.

2.8 Second Derivative Inflection Points

Finally, some authors have used a nonparametric regression analysis termed polynomial smoothing splines (Santos & Giannella-Neto, 2004; Sherrill et al., 1990; Wade et al., 1988). Polynomial smoothing splines use second derivatives to locate inflection points on a higher-order odd-degree polynomial equations. The inflection point of V_E/VO_2 vs. VO_2 corresponds to VT_1 and the inflection point of V_E/VCO_2 vs. VO_2 corresponds with RC.

2.9 Comparison of Different Ventilatory Threshold Assessment Techniques

As mentioned previously, there is no current gold standard for ventilatory threshold measurement procedure. In addition to the calculation method, determination of the second ventilatory threshold may also depend on other factors associated with the experimental protocol (Binder et al., 2008). Researchers have thus far noted differences in VT_1 for varied stage lengths (McLellan, 1985), for different modes of exercise (Davis, Vodak, Wilmore, Vodak, & Kurtz, 1976), and there were mixed results for ramp vs. step protocols (Zhang, Chow, & Wasserman, 1991; Zuniga et al., 2014). Far fewer studies

have compared if these variables affect RC determination, with one study noting no difference between 1-, 3-, and 5-minute step protocols (McLellan, 1985). Given how protocol differences may affect VT_1, it is plausible that further study may show such differences affect RC.

Besides the above, nearly all studies comparing different calculation methods examined VT_1 and not RC (Amann et al., 2004; Caiozzo et al., 1982; Ekkekakis et al., 2008; Fukuba, Munaka, UsuI, & Sasahara, 1988; Gallagher et al., 2014; Gaskill et al., 2001; Mehmet Kara et al., 1996; Schneider, Phillips, & Stoffolano, 1993; Zuniga et al., 2014). Of those, only one had a substantial sample size (Gaskill et al., 2001). Furthermore, RC was often determined at least in part by eye rather than objective methods (McLellan, 1985; Zhou & Weston, 1997). McLellan (1985) found that locating RC as determined by V_E vs. VCO_2, V_E/VCO_2 vs. VO_2, and the natural logarithms of both V_E/VO_2 vs. VO_2 and V_E/CVO_2 vs. VCO_2 showed no difference. Zhou found that a visual determination of RC was different from the results of the Dmax for both a test and retest, while a RC algorithm was significantly different from the Dmax at retesting only.

M Kara et al. (1999) found no differences between the Dmax and the conventional linear regression method using ventilatory equivalents. However, this study noted that the boundaries for their data were "the points that linear relation began and disappeared" (M Kara et al., 1999, p. 17), suggesting much of their data closer to VO_{2max} were omitted. This adjustment to the maximum suggests their use of the Dmax was intended to find VT_1.

Cheng et al. (1992) found that the V-slope method had a lower estimate of threshold values compared to the Dmax and linear regression methods. This may be attributed to Cheng finding RC with the Dmax and the V-slope finding VT_1. In addition, Cheng et al. (1992) found that RC as calculated by Orr et al. (1982) was not different from a ventilatory Dmax. However, Zhou and Weston (1997) conjectured that Cheng's calculation using Orr's method should have corresponded to VT_1. For that calculation, Cheng was only able to use a small sample of six subjects because two were not detectable by Orr's method. Finally, in Cheng's analysis (1992), the VO_2 at the ventilatory threshold was not statistically different from VO_2 at the OBLA, adding support to Zhou and Weston's assertion that the Dmax corresponds to VT_2.

Chapter 3: Methods

3.1 Study Design

This was a quasi-experimental, repeated measures design. Participant data from 2016-2018 was combined for analysis. Fitness testing procedures were identical during each year and at both pre and post timepoints except for VO_{2max} testing speeds. Pre-testing took place in early December at the end of the fall semester upon enrollment in the course. Post-testing data was collected at the end of each spring semester, within 1-2 weeks before students ran a marathon.

3.2 Participants

Healthy young adult students enrolled in a marathon training class were asked for their informed consent to have their fitness testing data used for research purposes. Use of data collected for classroom purposes was approved by the University of Minnesota IRB. Inclusion for fitness testing included medical clearance, absence of an extended history of stress fractures or other serious lower body injury or eating disorders. Inclusion for this study also included participation at both pre and post-fitness testing.

3.3 Marathon Training

Prior to testing at the start of the spring semester, students followed a six-week training program starting in mid-December. Each student self-selected one of three plans based on previous running experience: Novice, Intermediate, or Advanced (Appendix 7.3-7.5). All running during the winter training plan was considered “easy” or “base” mileage, defined as running at a comfortable, conversational pace.

Upon starting the spring semester, students followed a training program that consisted of 4-5 days a week of running, 2 of which were supervised (Appendix 6). One supervised day was a long run and the other was a high intensity workout such as hills, tempo/threshold, fartlek, or intervals. In the appendix, AT signified “anaerobic threshold.” Other running was performed outside of class at an easy pace. Over the course of the semester, prescribed weekly mileage increased until tapering two weeks

before the marathon. The average prescribed mileage was 96 minutes per week Monday-Saturday with an average 13.75-mile long run on Sunday.

3.4 Exercise Testing

One to two weeks prior to VO_{2max} testing, participants performed a 2-mile time trial run on a standardized indoor 200-meter track to establish a baseline level of fitness and to capture changes in running fitness over time. The results of the 2-mile time trial were used to generate the speeds for each participant during the VO_{2max} testing protocol. A 2-mile time trial is a valid field test of aerobic fitness and is highly correlated to treadmill VO_{2max} in both men and women (Mello, Murphy, & Vogel, 1988).

Variables at the second threshold such as speed or $\%VO_{2max}$ are also among the best predictors endurance races ranging from both a 3k to a marathon (Grant, Craig, Wilson, & Aitchison, 1997). A 2-mile time trial was also useful as a field test because it is comparable to a 3k since 2-miles is only slightly more (~219 meters) than one additional lap (200 meters) on an indoor track. Given the similarity of the two distances, second threshold variables are also likely among the best predictors of 2-mile performance. However, a 2-mile was chosen over a 3k because participants were thought to conceptualize this distance because miles are standard length units in the United States. Because most participants improved in their 2-mile time trial, post-testing VO_{2max} treadmill speeds were generally higher than pre-testing speeds. This provided a better physiological match between testing conditions.

Before VO_{2max} testing, subjects were instructed to avoid hard exercise for 12 hours, to avoid alcohol, tobacco, and caffeine for 8 hours, and to avoid eating for 3-4 hours. Upon arrival, students completed a medical history questionnaire and consent form to allow their data to be used for research purposes. Following this, anthropometric measurements were taken.

Modeled after Brown (2013), subjects walked for one minute at 3 miles per hour before running for six minutes at a treadmill speed of 75% of their average 2-mile time trial speed. The purposed of this stage was to gather data to assess steady-state variability and running economy. Following those six minutes, speed was increased progressively each minute to 80, 85, 95, and 100% of their average 2-mile time trial speed. All speeds

were rounded to the nearest tenth of a mile per hour. After reaching average 2-mile time trial speed, the grade increased by 1.5% each minute until volitional fatigue. Participants were considered to have attained their VO_{2max} if they met at least two of the following criteria: ≥ 90% of predicted maximum heart rate (220–age), RER ≥ 1.1, or > 16 on the Borg RPE scale (Borg, 1998). During treadmill testing, all participants wore Polar RS800 watches (Kempele, Finald) to record heart rate.

3.5 Measurement of Pulmonary Gas Exchange Variables

Prior to VO_{2max} testing, gasses were calibrated via Ultima CPX metabolic cart (MCG Diagnostics, St. Paul, MN) against two known gas compositions. The first was 5% CO_2, 12% O_2, with balance N_2, and the second was 21% O_2 with balance N_2. preVENT® facemasks flows sensors (MCG Diagnostics, St. Paul, MN) were calibrated against a 3 L syringe prior to testing. Calibrations were adjusted for room temperature, barometric pressure, and relative humidity. Participants wore these sensors along with preVENT® facemasks and couplers during testing (MCG Diagnostics, St. Paul, MN). All pulmonary gasses were collected breath-by-breath and analyzed via Ultima CPX metabolic cart (MCG Diagnostics, St. Paul, MN).

3.6 Computerized RC Calculation Methods

A total of four computerized methods were tested to find RC. All methods were employed using WinBreak 3.7 software. The four methods were the Jones and Molitoris, Orr, and Beaver V-slope breakpints, and Cheng's Dmax method. All methods were applied to the V_E vs. VCO_2 graph.

3.7 Determination of Respiratory Compensation Point and VO_{2max}

Unaveraged data was collected from exercise testing was downloaded to Microsoft Excel. Data was then uploaded to WinBreak 3.7 for further analysis. Using WinBreak software, data was cleaned to remove outliers, and then averaged to every 20 seconds. In order to apply breakpoint and Dmax methods using Winbreak, the start and end points of the data were trimmed to match regular 1-minute increase in exercise intensity. As such, the beginning of the analysis started at the last minute of the steady-

state stage and ended at voluntary exhaustion. The 6-minute steady state portion of this protocol begins at an intensity of approximately 65% of VO_{2max}, which may be at or above VT_1 (Davis, Frank, Whipp, & Wasserman, 1979; Ready & Quinney, 1982; Skinner & Mclellan, 1980). As such, VT_1 was not determined.

After determining the timepoint of the V_E vs. VCO_2 breakpoint, a plot of 20-second average VO_2 vs. time was made using Microsoft Excel. Then, a linear regression in the form of $y = ax + b$ was fit to this relationship where $y = VO_2$ and $x =$ time. The timepoint of RC was then entered and the resulting VO_2 was documented. This procedure was included to reduce the contribution of any variability that would reduce the VO_2 despite increased testing intensity. If a VO_2 plateau or systematic decrease in VO_2 was observed near test termination, the data points following the first point in the plateau or downturn were removed. VO_{2max} was defined as the highest 20-second average VO_2.

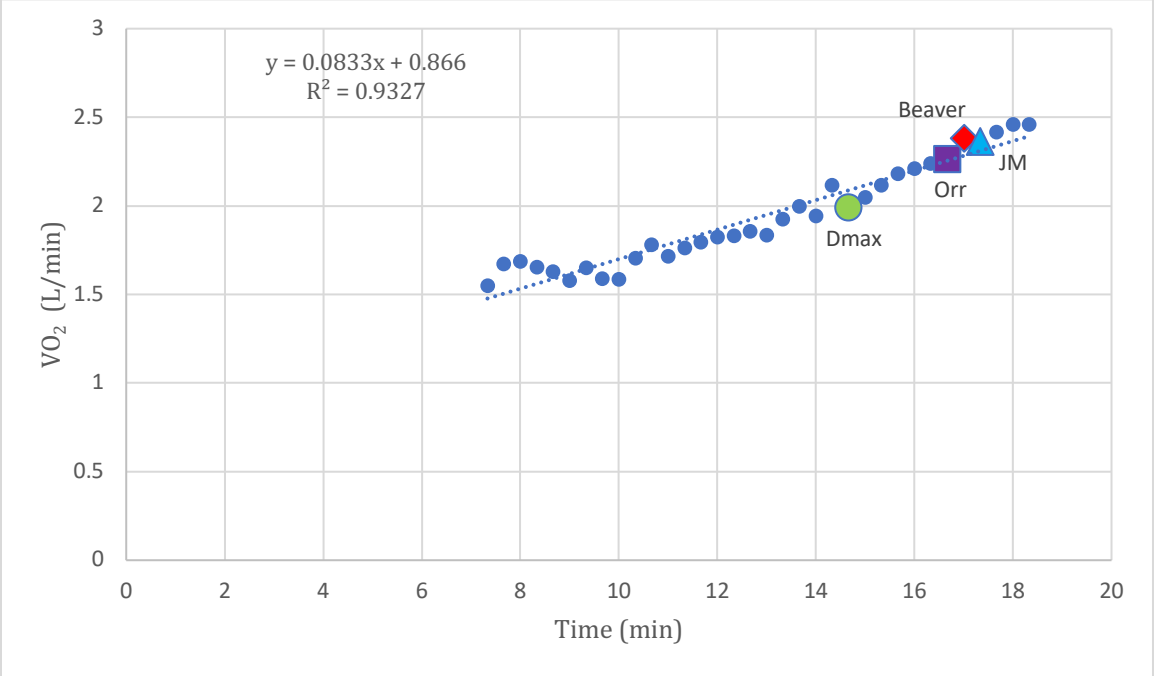

Figure 1: 20-second averages of VO2 vs. time. The VO2 for each method was calculated using the best linear fit. The larger green circle is the timepoint for Dmax, the purple square for Orr, the red diamond for Beaver, and the light blue triangle for JM.

Finally, WinBreak will find a solution to satisfy the criteria of the breakpoint algorithms, even if a respiratory compensation was not demonstrated by a given participant. Therefore, it was determined *a priori* that subjects demonstrated respiratory

compensation when the V_E vs. VCO_2 in slope increased by at least 10% and the mean square error from the single to the double regression lines decreased by at least 10%. Those cases that did not satisfy these 10% changes were marked as indeterminate. Indeterminate cases were not included in later statistical analysis involving calculations of RC or VO_{2max}. Figure 2 shows an example of determinate and indeterminate cases.

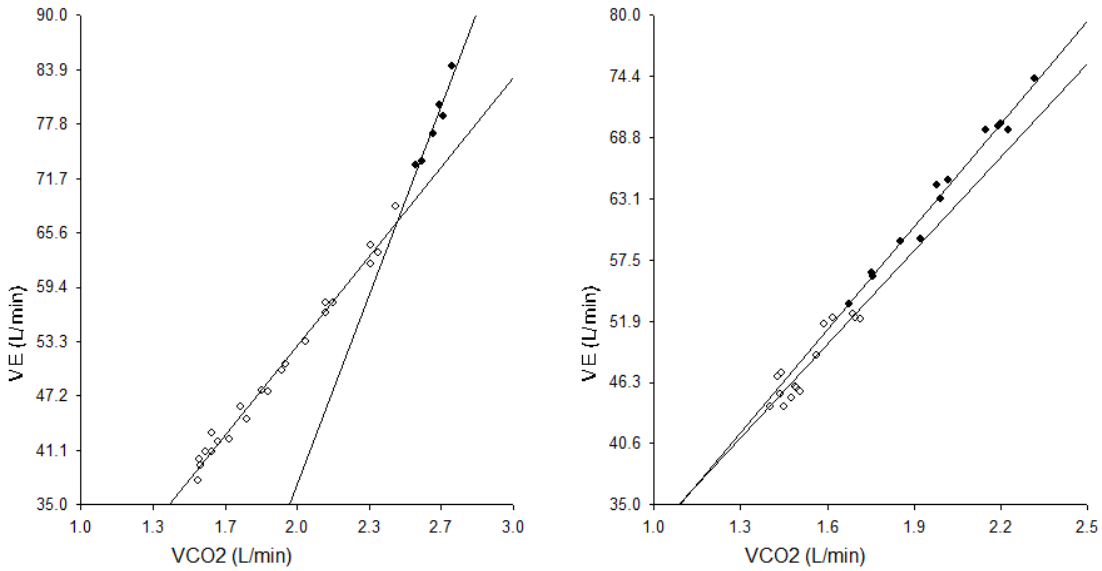

Figure 2: Graphs from WinBreak 3.7 that show examples of determinate (left) and indeterminate (right) cases.

3.8 Statistical Analysis

The statistical software R (version 3.5.3), RStudio (version 1.2.1335) as well as R packages BlandAltmanLeh, car, ggplot2, lattice, lme4, lmerTest, performance, psych, and tidyverse were used to perform the following statistical analyses (Bates, Martin, Bolker, & Walker, 2015; Fox & Weisberg, 2011; Kuznetsova, Brockhoff , & Christensen, 2017; Lehnert, 2015; Lüdecke & Makowski, 2019; R Core Team, 2019; Revelle, 2018; RStudio Team, 2018; Sarkar, 2008; Wickham, 2016, 2017). To compared difference in detection rates, percent determinate rates for pre, for post, and for both pre and post were calculated for each method. In addition, Fisher's exact tests were used on 2x2 tables for each method and each time point. These tables included counts of determinate and indeterminate readings at both pre and post timepoints. Fisher exact tests were chosen to assess if there was a nonrandom association between an RC method finding a determinate

or indeterminate result at both pre and post timepoints. That is, it tested the relationship between an RC method producing a determinate result at both timepoints. Finally, a bootstrap resampling was performed on determinate results at pre, at post, and at both pre and post for each method. Bootstrap resampling was repeated 10,000 times. Resampling data was plotted on overlapping histograms to visually assess differences in detection rates between methods.

The $\%VO_2max$ at RC of automatic methods were compared using a linear mixed effects model (LMEM). A likelihood ratio test compared iterations of each LMEM. Iterations included random effects for timepoint and the fixed effects of timepoint, method, body mass, age, sex, and their interactions. A new model was chosen if the likelihood ratio test provided a significant p-value and if it explained more variance than the previous model. Models were also compared using Akaike and Bayesian information criterion (AIK and BIK, respectively), marginal and conditional R^2, and root mean square error (RMSE). Statistical significance of main effects for the fixed effects in each model were assessed with a t-test.

Pearson's correlation coefficients were also calculated to compare each method to each other and to 2-mile time trial performances. Limits of agreement (LOA) were also quantified between each method at the same timepoint and between timepoints for the same method. The 95% LOA was defined as 2 standard deviations (Bland & Altman, 1986). Body mass, absolute and relative VO_{2max} and 2-mile time trials were compared between males and females using independent t-tests. Pre-post differences in absolute and relative VO_{2max}, body mass, and 2-mile times were assessed with paired t-tests for both sexes separately and combined. α was set to 0.05.

Chapter 4: Results

4.1 VO_{2max}, Body Mass, and 2-mile Performance

Body mass, absolute, and relative VO_{2max} were not significantly different after training when considering males and females separately or combined. Although there were no improvements in VO_{2max}, runners were significantly faster in the post 2-mile time trial (Table 1). As expected, males had significantly larger body mass, larger absolute and relative VO_{2max}, as well as faster 2-mile times than females.

*Table 1: Changes in VO_{2max}, 2-mile time trial performance, and body mass (BM). Results are mean ± (SD). *** significant at $p < 0.001$ compared to pre testing. † significant at $p < 0.001$ compared to the opposite sex at the same timepoint. n = 32 for male pre 2-mile, n = 55 for females pre 2-mile, and n = 87 for combined 2-mile.*

Combined (n = 89)	**VO_{2max} (L/min)**	**VO_{2max} (mL/kg/min)**	**2-mile (min)**	**BM (kg)**
Pre	3.16 (0.69)	47.16 (6.83)	16.23 (2.24)	66.81 (9.75)
Post	3.21 (0.74)	47.70 (7.2)	14.70 (1.76)***	66.89 (9.27)
Males (n = 33)	**VO_{2max} (L/min)**	**VO_{2max} (mL/kg/min)**	**2-mile (min)**	**BM (kg)**
Pre	3.89 (0.50)†	52.70 (5.95)†	14.84 (2.12)†	74.14 (9.24)†
Post	3.91 (0.64)†	52.99 (6.80)†	13.37 (1.58)***†	73.85 (8.2)†
Females (n = 56)	**VO_{2max} (L/min)**	**VO_{2max} (mL/kg/min)**	**2-mile (min)**	**BM (kg)**
Pre	2.73 (0.35)†	43.9 (4.97)†	17.04 (1.89)†	62.49 (7.15)†
Post	2.79 (0.4)†	44.58 (5.42)†	15.49 (1.34)***†	62.79 (7.23)†

4.2 Determination Rates

The analysis of determination rates indicated a consistent pattern among the four methods. The order of highest to lowest determination rates was JM, Dmax, Orr, and Beaver. This order was the same when considering determinate results only at pre, only at post, or when considering pre and post combined (Table 2). There were also fewer determinate cases at post testing than at pre testing for all methods. Combined pre and post determinate rates were smaller yet, regardless of method. This was because some methods found participants as determinate at pre but not at post and vice versa (Table 2).

Table 2: Determination rates for each method, for each time point, and for combined of timepoints. Data is expressed as counts and percentages (%) of total for a given condition.

Timepoint	Result	JM	Orr	Beaver	Dmax
Pre	**Determinate**	96 (73.3%)	91 (69.5%)	68 (51.9%)	93 (71.0%)
	Indeterminate	35 (26.7%)	40 (30.5%)	63 (48.1%)	38 (29.0%)
Post	**Determinate**	82 (62.6%)	69 (52.7%)	45 (34.4%)	77 (58.8%)
	Indeterminate	49 (37.4%)	62 (47.3%)	86 (65.6%)	54 (41.2%)
Pre and Post	**Determinate**	67 (51.1%)	56 (42.0%)	28 (21.4%)	63 (48.1%)
	Indeterminate	64 (48.9%)	75 (57.3%)	103 (78.6%)	69 (51.9%)

Fisher exact tests found that all but the Beaver method had a true odds ratio significantly higher from 1 (Figure 3). Bootstrap resampling histograms depicted minimal overlap between Beaver and any other method, regardless of timepoint (Figure 3). Overlap between JM, Orr, and Dmax methods was consistently high for pre, post, and combined pre-post conditions, but was highest at pre testing. Of the original 131 subjects (45 males, 86 females), 89 (33 males, 56 females) had a method find a determinate RC at

Table 3: 2x2 tables for Fisher's exact tests with odds ratios (OR) and p-values. Determinate (D) and indeterminate (I) data is expressed as counts and as percentages (%) of total among all cells (n = 131) in the table.

JM		**Post**	
***p* < 0.05**	**OR = 3.05 (1.29 - 7.41)**	**D**	**I**
Pre	**D**	67 (51.1%)	29 (22.1%)
	I	15 (11.5%)	20 (15.3%)

Orr		**Post**	
***p* < 0.005**	**OR = 3.29 (1.42 - 7.95)**	**D**	**I**
Pre	**D**	56 (42.7%)	35 (26.7%)
	I	13 (9.9%)	27 (20.6%)

Beaver		**Post**	
***p* > 0.05**	**OR = 1.88 (0.85 - 4.25)**	**D**	**I**
Pre	**D**	28 (21.4%)	40 (30.5%)
	I	17 (13.0%)	46 (35.1%)

Dmax		**Post**	
***p* < 0.005**	**OR = 3.56 (1.53 - 8.61)**	**D**	**I**
Pre	**D**	63 (48.1%)	30 (22.9%)
	I	14 (10.7%)	24 (18.3%)

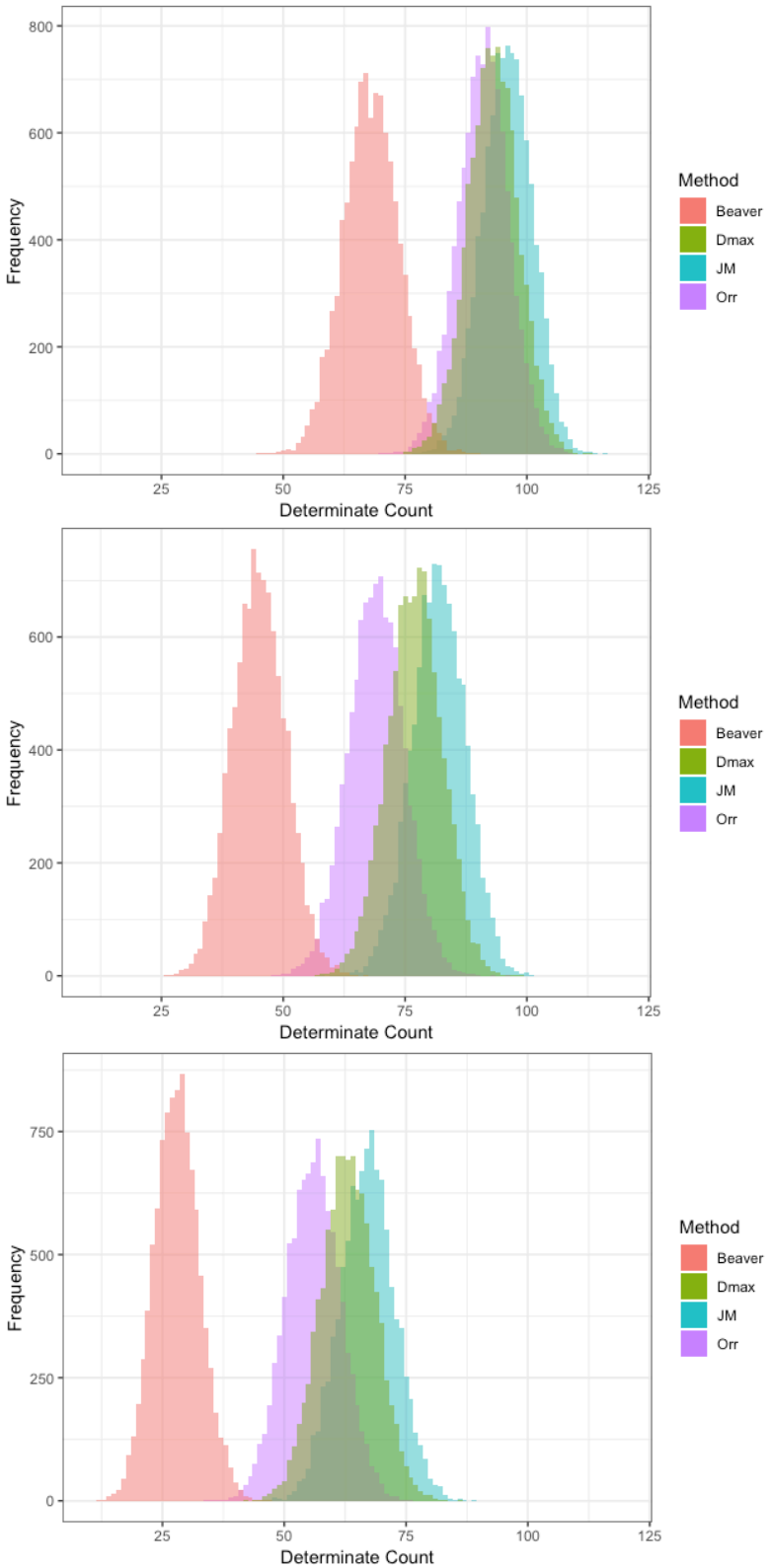

Figure 3: Overlapping histograms from bootstrap resampling of determinate samples at pre (top), post (middle), and both pre and post (bottom). Determinate count is the number of determinate cases in a given bootstrap sample.

both pre and at post testing. The gas exchange data from these 89 remaining individuals would be used compare automated RC methods. A Fisher's exact test indicated that the counts of males to females did not significantly differ after eliminating individuals who lacked determinate values for all methods at pre, at post, or at both pre and post testing. ($p = 0.77$, OR = 0.49 – 1.61).

4.3 Linear Mixed Effects Model

The final LMEM (model 9 in Table 4) included a random intercept for each individual, a random slope for time, and a fixed effect for method ($p < 0.05$). Compared to the null model, this model reduced residual variance by 60.82%. This model

was chosen as the final model over model 8 because model 9 reduced more residual variance and had a lower AIC, BIC, and RMSE. Model 9 had a lower marginal R^2 but had an identical conditional R^2 compared to model 8.

Fixed effects and random slopes for sex, age, or body mass were not included in the final model because including those variables did not result in a significant likelihood ratio test ($p > 0.05$) compared to the null model. The likelihood ratio test was significant for adding a fixed effect for time (model 6), but this was not selected as the final model because the AIC, BIC, and RMSE were all higher when compared to model 9. Model 6 had a lower condition R^2 and also explained less residual variance than model 9.

When controlling for time using model 9, there was a significant main effect for method such that the $\%VO_{2max}$ at RC for the JM method was significantly higher than both Beaver ($p < 0.05$) and Dmax ($p < 0.01$) methods while approaching a significantly higher result compared to Orr's method ($p = 0.06$). This difference was confirmed by setting each method as the reference group. Model 9 in table 4 depicts JM at pre testing as the reference group.

The fitted vs. residuals plot of model 9 indicated linearity but also heterogeneity of variance at values below ~80% VO_{2max} (Figure 4). Residuals followed a normal distribution (Figures 5 and 6).

Table 4: LMEM hierarchical design. The top row in the fixed effects column for each model is the intercept for that model.

Model #	Test model	Comparison model	Likelihood ratio test	Fixed Effects	Estimate	Standard Error	p-value	Random Effects	Variance	% variance explained against null	AIC	BIC	R^2 Cond	R^2 Marg	RMSE
1	Random: Intercept (Null)	–	–	Intercept	88.91	0.50	< 0.001	Intercept	18.28	–	3445	3458	0.43	0	4.57
								Residual	24.10	–					
2	Fixed: Sex Random: Intercept	1	$\chi^2(1) = 0.63$ p = 0.42	Male	89.42	0.81	< 0.001	Intercept	18.13	0.82	3447	3464	0.43	0.00	4.57
				Female	-0.83	1.03	0.43	Residual	24.10	0.00					
3	Fixed: Body Mass Random: Intercept	1	$\chi^2(1) = 2.72$ p = 0.10	Intercept	83.31	3.38	< 0.001	Intercept	17.35	5.09	3444	3462	0.43	0.02	4.58
				BM	0.084	0.05	0.10	Residual	24.15	-0.21					
4	Fixed: Age Random: Intercept	1	$\chi^2(1) = 1.87$ p = 0.17	Intercept	77.10	8.59	< 0.001	Intercept	17.78	2.74	3445	3462	0.43	0.01	4.57
				Age	0.56	0.41	0.17	Residual	24.11	-0.04					
5	Fixed: Method Random: Intercept	1	$\chi^2(3) = 4.11$ p = 0.25	JM	89.56	0.60	< 0.001	Intercept	18.31	-0.16	3447	3472	0.44	0.00	4.55
				Orr	-0.75	0.58	0.19								
				Beaver	-0.95	0.64	0.14	Residual	23.89	0.87					
				Dmax	-1.054	0.56	0.06								
6	Fixed: Time Random: Intercept	1	$\chi^2(1) = 7.64$ p < 0.01	Pre	87.18	0.80	< 0.001	Intercept	18.53	-1.37	3440	3457	0.44	0.01	4.53
				Post	1.19	0.43	< 0.01		23.66	1.83					

Table 4 (continued): LMEM hierarchical design. The top row in the fixed effects column for each model is the intercept for that model.

Model #	Test model	Comparison model	Likelihood ratio test	Fixed Effects	Estimate	Standard Error	p-value	Random Effects	Variance	% variance explained against null	AIC	BIC	R^2 Cond	R^2 Marg	RMSE
7	Fixed: Time + Method Random: intercept	6	$\chi^2(3) = 3.85$ $p = 0.28$	JM, Pre	87.83	0.87	< 0.001	Intercept	18.55	-1.46	3442	3472	0.45	0.01	4.51
				Orr	-0.71	0.57	0.22								
				Beaver	-0.85	0.63	0.18								
				Dmax	-1.04	0.56	0.06	Residual	23.47	2.61					
				Post	1.17	0.43	< 0.01								
8	Fixed: Time Random: Time Slope + Intercept	1	$\chi^2(3) = 230.17$ $p < 0.001$	Pre	87.10	1.37	< 0.001	Intercept	150.81	–	3221	3247	0.78	0.01	2.62
								Time	49.48	–					
				Post	1.14	0.80	0.16	Sum	200.29	–					
								Residual	9.66	59.90					
9	Fixed: Method Random: Time Slope + Intercept	1	$\chi^2(3) = 8.65$ $p < 0.05$	JM	89.51	0.55	< 0.001	Intercept	153.41	–	3218	3253	0.79	0.00	2.59
				Orr	-0.70	0.06	> 0.05	Time	50.90	–					
				Beaver	-0.97	0.41	0.06	Sum	204.31	–					
				Dmax	-0.93	0.36	< 0.01	Residual	9.44	60.82					
10	Fixed: Method + Time Random: Time Slope + Intercept	9	$\chi^2(3) = 1.88$ $p = 0.17$	JM, Pre	87.75	1.39	< 0.001	Intercept	150.45	–	3219	3257	0.79	0.01	2.59
				Orr	-0.69	0.37	0.07	Time	49.66	–					
				Beaver	-0.96	0.41	< 0.05	Sum	200.12	–					
				Dmax	-0.93	0.36	< 0.01	Residual	9.44	60.82					
				Post	1.10	0.80	0.17								

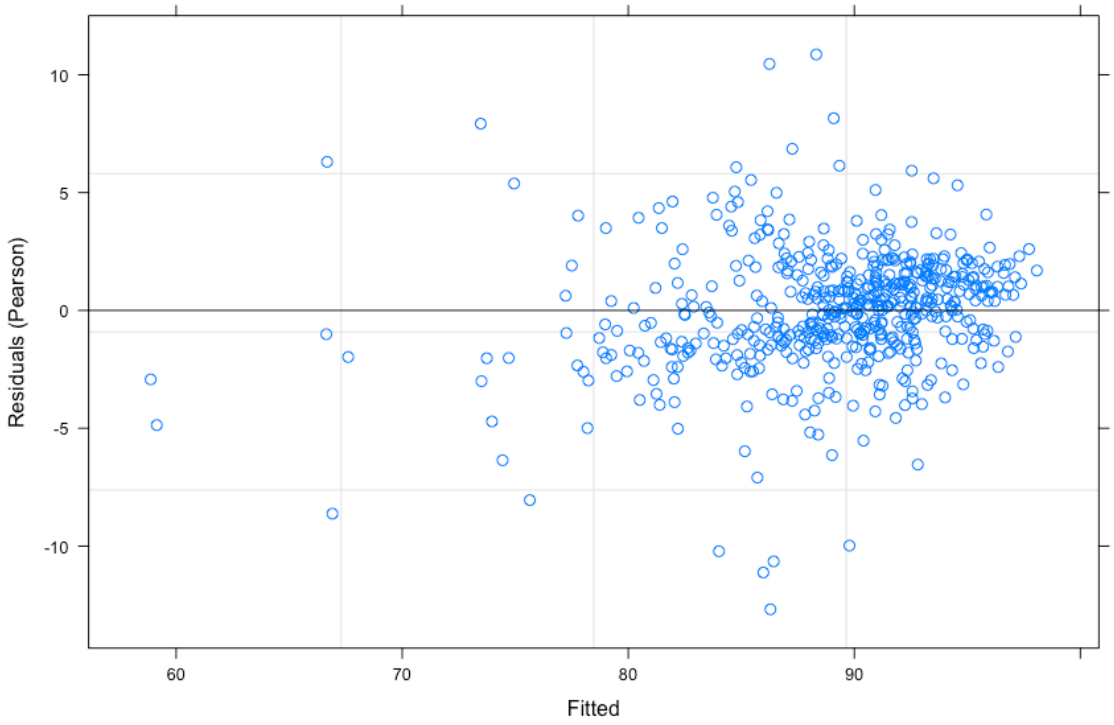

Figure 4: Residuals vs. fitted to assess linearity, heteroskedasticity, and homogeneity of variance.

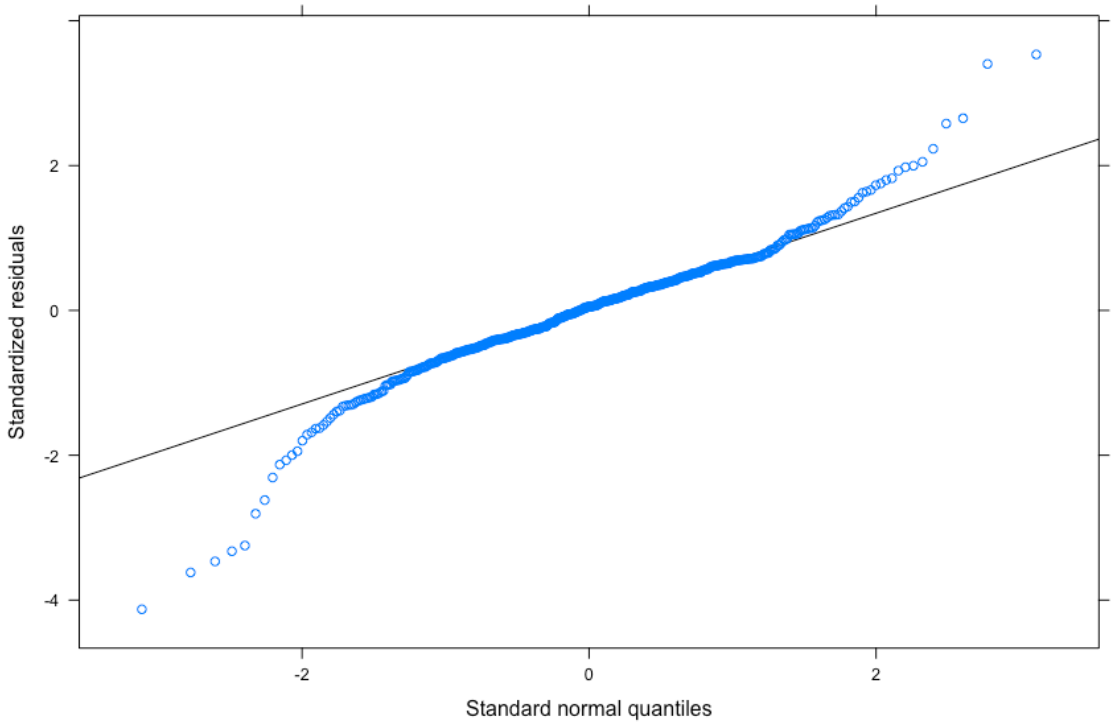

Figure 5: Quantile-Quantile (Q-Q) plot to assess normality.

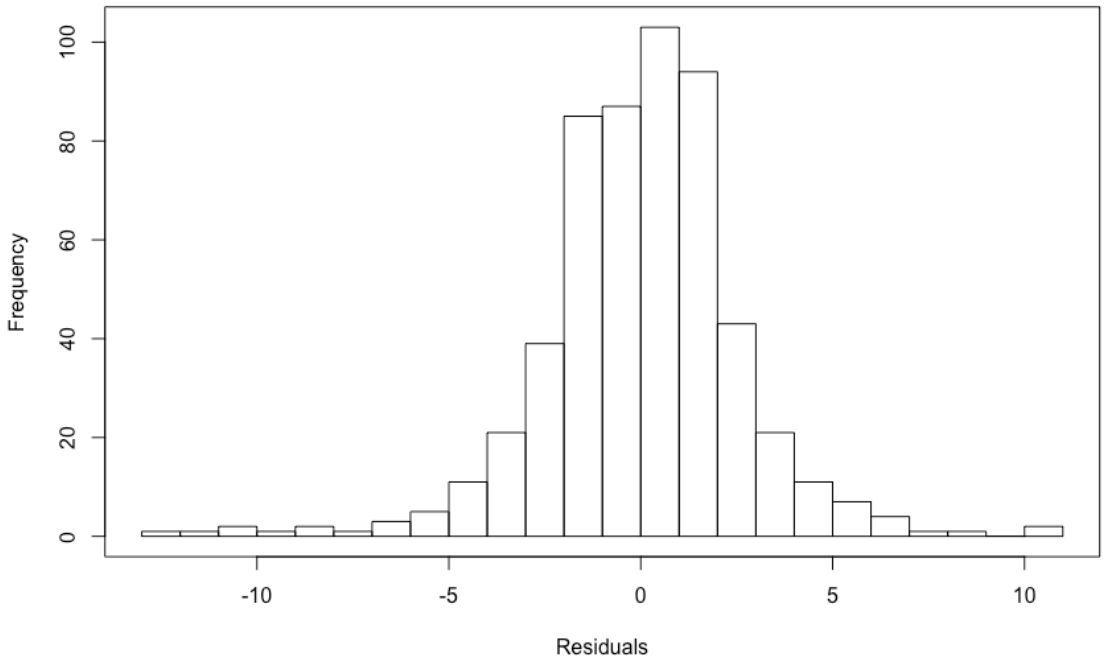

Figure 6: Histogram of LMEM residuals to assess normality.

4.4 Correlations and Agreement Between Methods

Correlation analysis revealed significant, positive, and strong ($r > 0.7$) correlations between all methods ($p < 0.001$). At pre testing, all methods but Dmax were significantly ($p < 0.05$), negatively, and weakly ($r < –0.3$) correlated with 2-mile performance (Table 4). At post testing, all methods were significantly and positively correlated with one another ($p < 0.001$). The correlations between Orr and Dmax and between Orr and JM were moderate ($0.3 \leq r \leq 0.7$) whereas all other correlations between methods were strong ($r > 0.7$). At post testing, no method was significantly correlated with 2-mile time trial performance.

Bland-Altman plots confirmed heterogeneity of variance in all but the JM-Orr and Orr-Beaver plots at post testing (Table 6, Figure 7, Figure 10). At pre testing only, the JM method was biased higher than the three other methods. The JM method post-pre and all comparisons against the Dmax showed an upward trend (Figures 9, 11-12). Finally, the mean 95% LOA for comparisons between methods was 15.69. The mean 95% LOA for post-pre comparisons within the same method was 32.95.

*Table 5: Pearson correlations coefficients between different methods and with 2-mile time trials at pre and post testing. * significant < 0.05. *** significant < 0.001*

Pre	**Beaver**	**Dmax**	**JM**	**Orr**	**2-mile**
Beaver					
Dmax	0.70 (n = 57)***				
JM	0.86 (n = 58)***	0.80 (n = 75)***			
Orr	0.78 (n = 55)***	0.78 (n = 68)***	0.83 (n = 69)***		
2-mile	-0.26 (n = 59)*	-0.16 (n = 77)	-0.25 (n = 79)*	-0.24 (n = 76)*	
Post	**Beaver**	**Dmax**	**JM**	**Orr**	**2-mile**
Beaver					
Dmax	0.73 (n = 35)***				
JM	0.91 (n = 38)***	0.79 (n = 65)***			
Orr	0.75 (n = 32)***	0.66 (n = 53)***	0.67 (n = 53)***		
2-mile	0.24 (n = 41)	0.11 (n = 71)	0.1 (n = 75)	0.01 (n = 64)	

Table 6: Bland-Altman plot statistics and interpretation. Limits of agreement (LOA) is the width of 95% confidence intervals. Bias is the average difference from the first to second group.

Pre	Heterogeneity of Variance	Bias	Trend	LOA	n
JM-Orr	Yes	1.80	–	15.63	69
JM-Beaver	Yes	1.36	–	13.25	58
JM-Dmax	Yes	1.30	Upward	14.98	75
Orr-Beaver	Yes	0	–	21.70	55
Orr-Dmax	Yes	0	Upward	18.17	68
Beaver-Dmax	Yes	0	Upward	16.89	57
Post	**Heterogeneity of Variance**	**Bias**	**Trend**	**LOA**	**n**
JM-Orr	No	0	–	15.64	53
JM-Beaver	Yes	0	–	10.02	38
JM-Dmax	Yes	0	Upward	15.74	65
Orr-Beaver	No	0	–	17.23	32
Orr-Dmax	Yes	0	Upward	17.04	53
Beaver-Dmax	Yes	0	Upward	15.07	35
Post-Pre Difference	**Heterogeneity of Variance**	**Bias**	**Trend**	**LOA**	**n**
JM	Yes	0	Upward	31.21	67
Orr	Yes	0	–	39.77	56
Beaver	Yes	0	–	39.82	28
Dmax	Yes	0	–	21.01	63

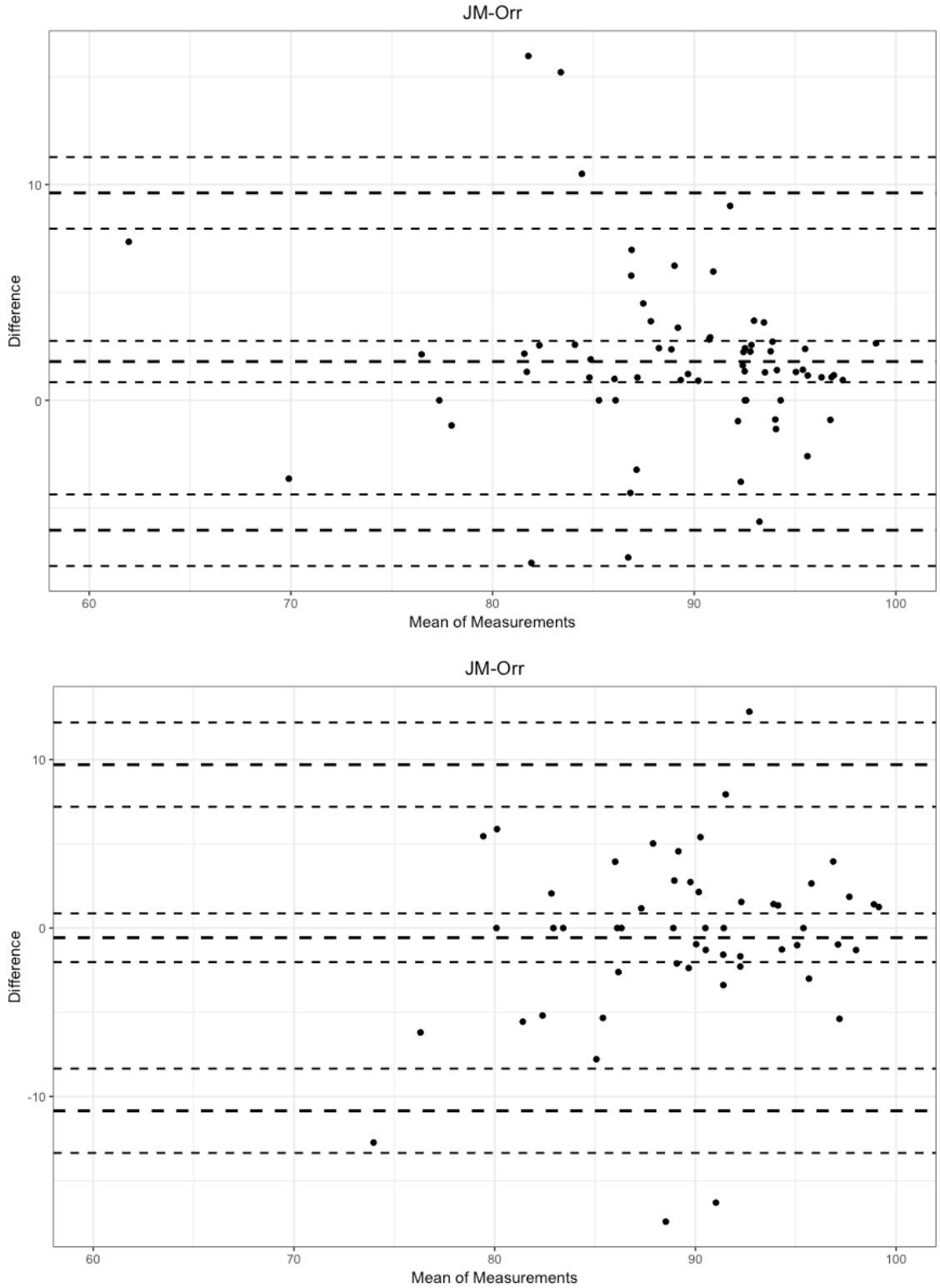

Figure 7: Bland-Altman plots for pre (top) and post (bottom) JM-Orr comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

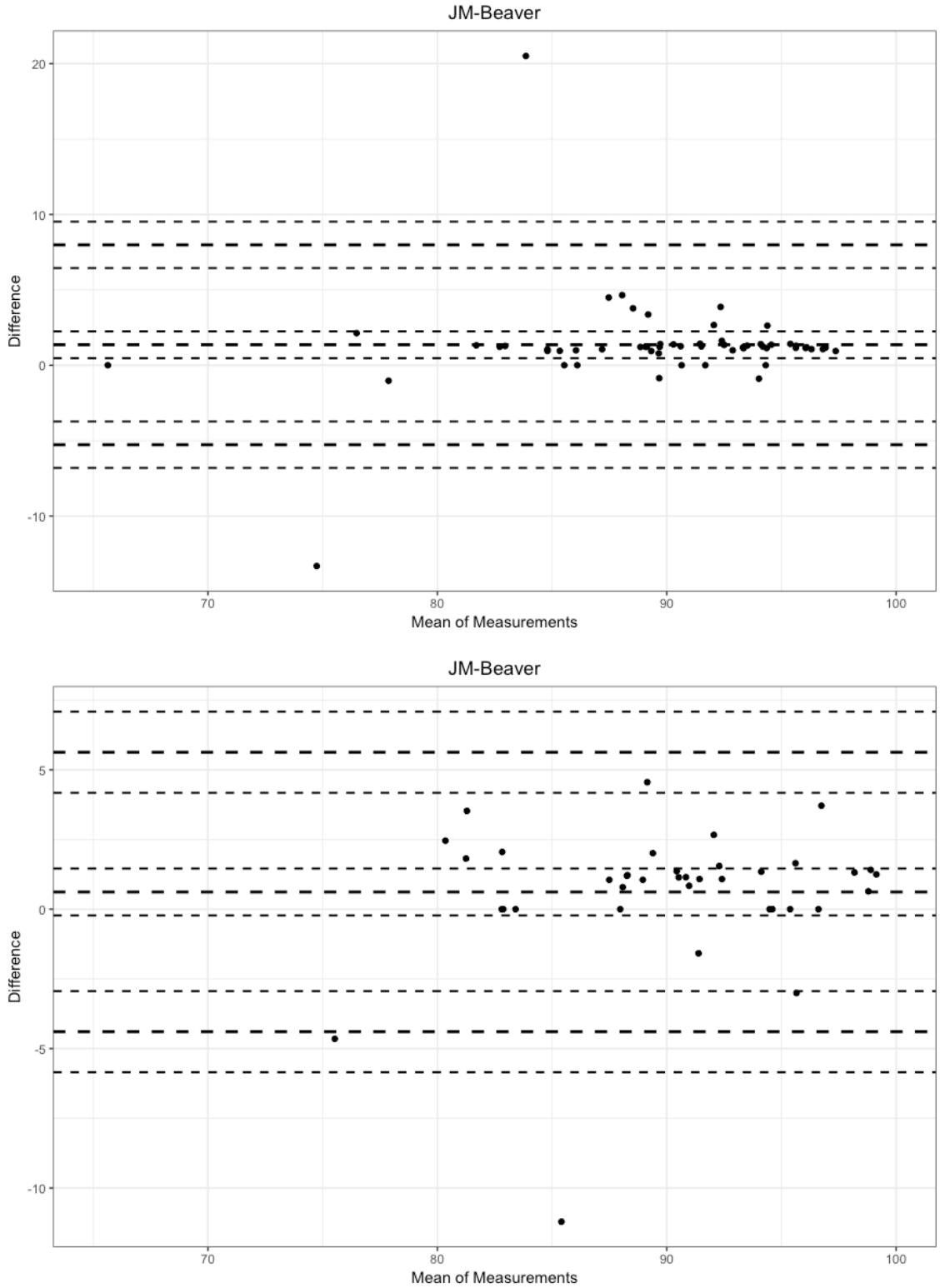

Figure 8: Bland-Altman plots for pre (top) and post (bottom) JM-Beaver comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

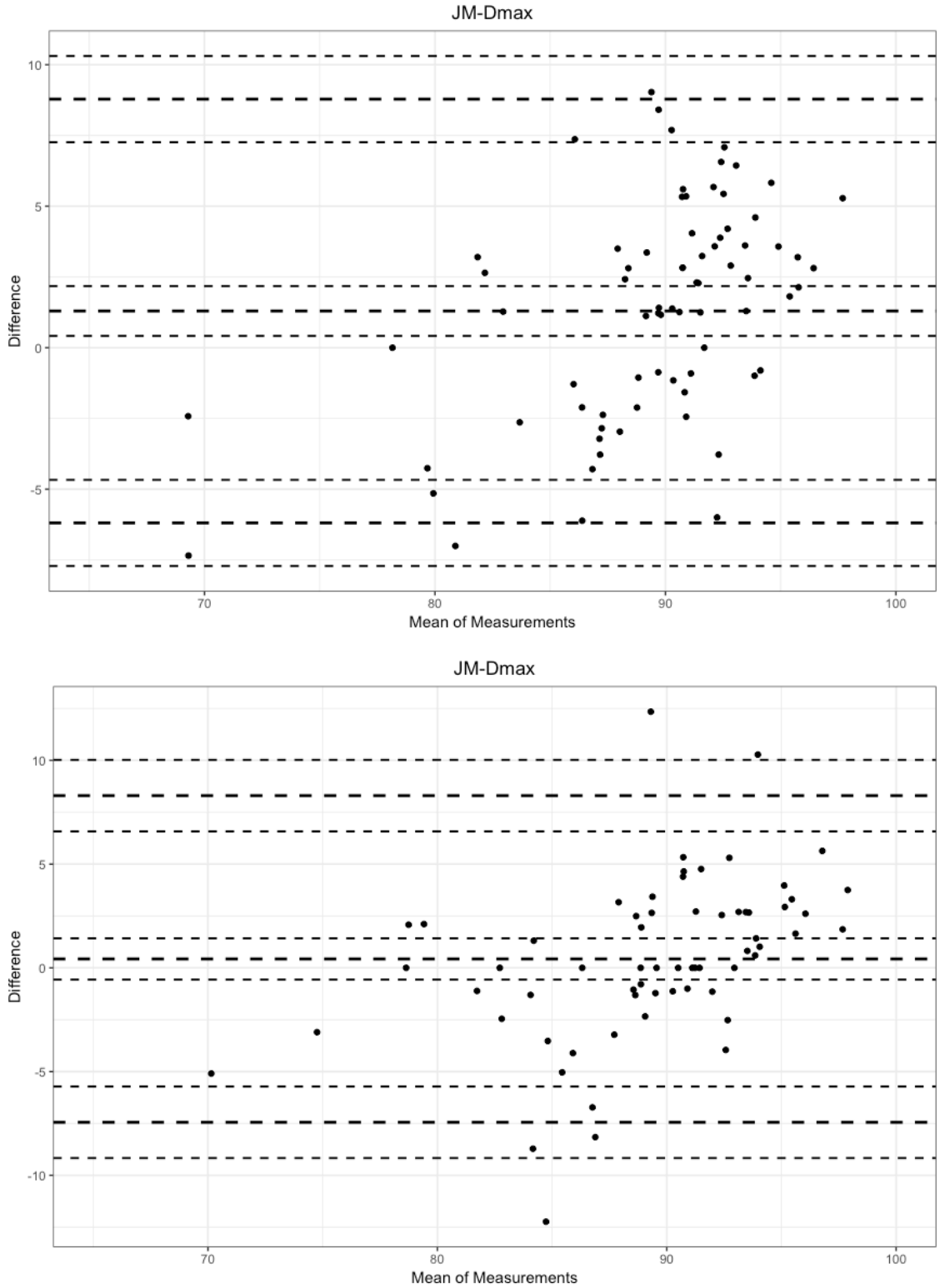

Figure 9: Bland-Altman plots for pre (top) and post (bottom) JM-Dmax comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

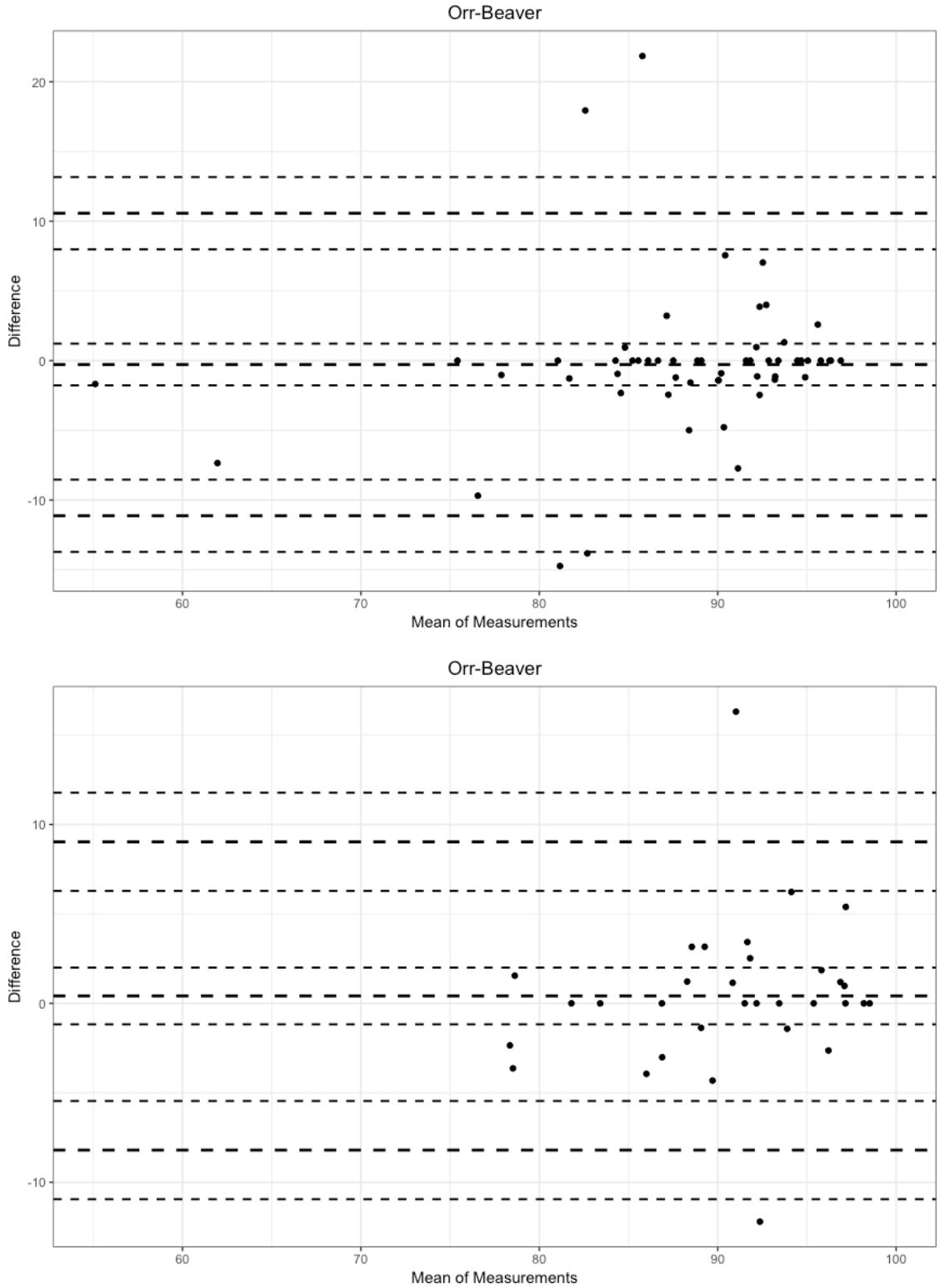

Figure 10: Bland-Altman plots for pre (top) and post (bottom) Orr-Beaver comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

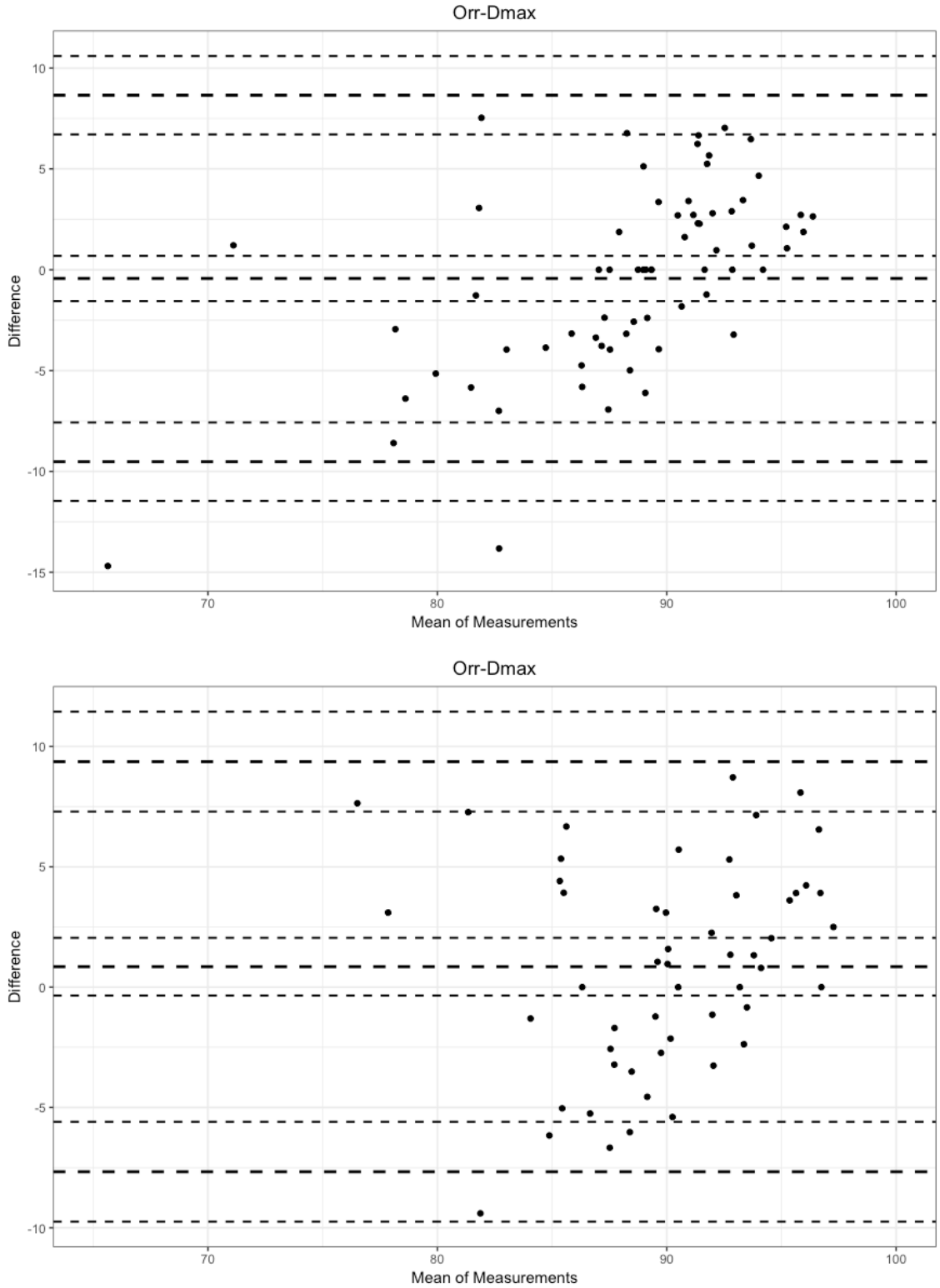

Figure 11: Bland-Altman plots for pre (top) and post (bottom) Orr-Dmax comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

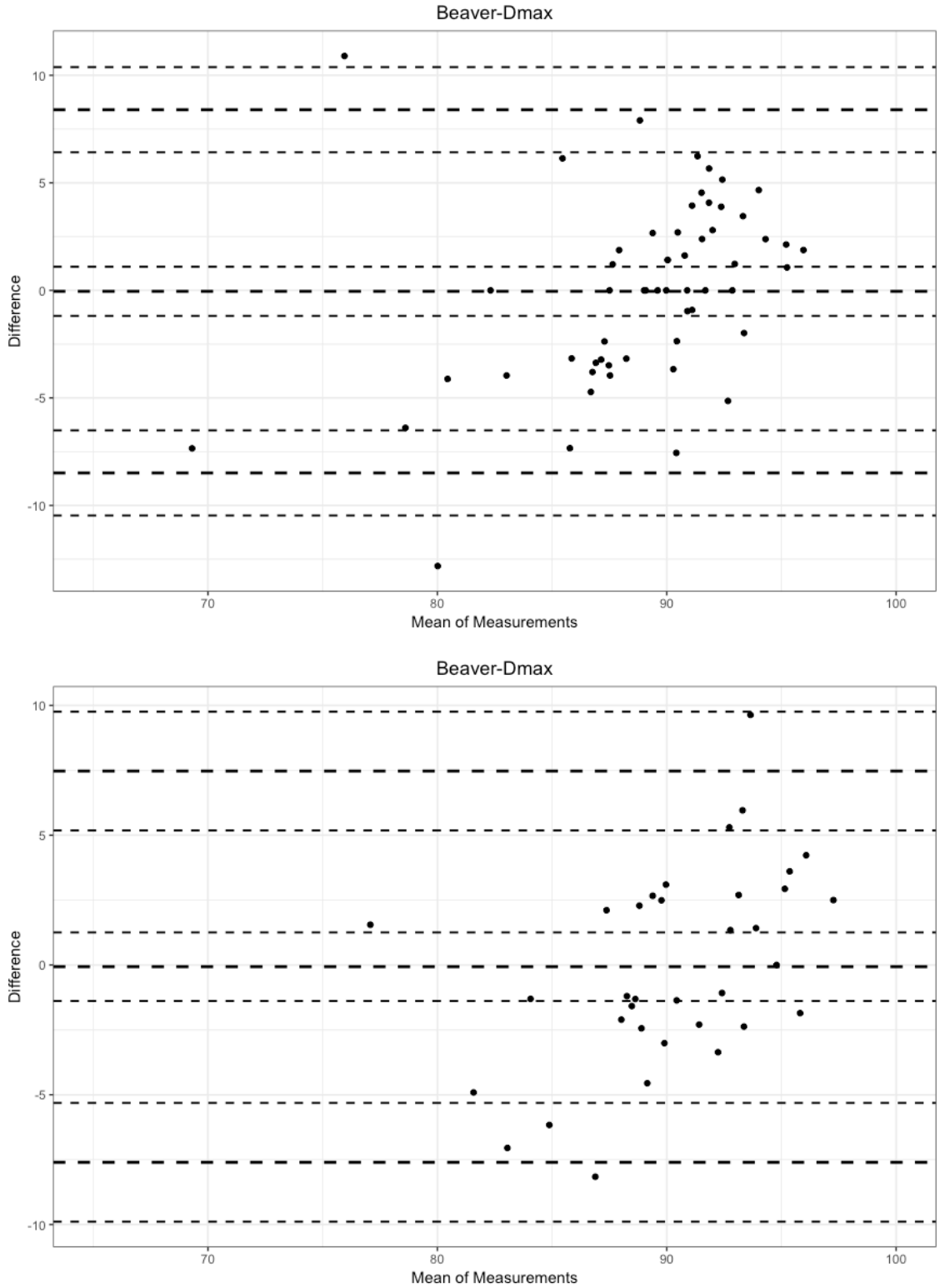

Figure 12: Bland-Altman plots for pre (top) and post (bottom) Beaver-Dmax comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

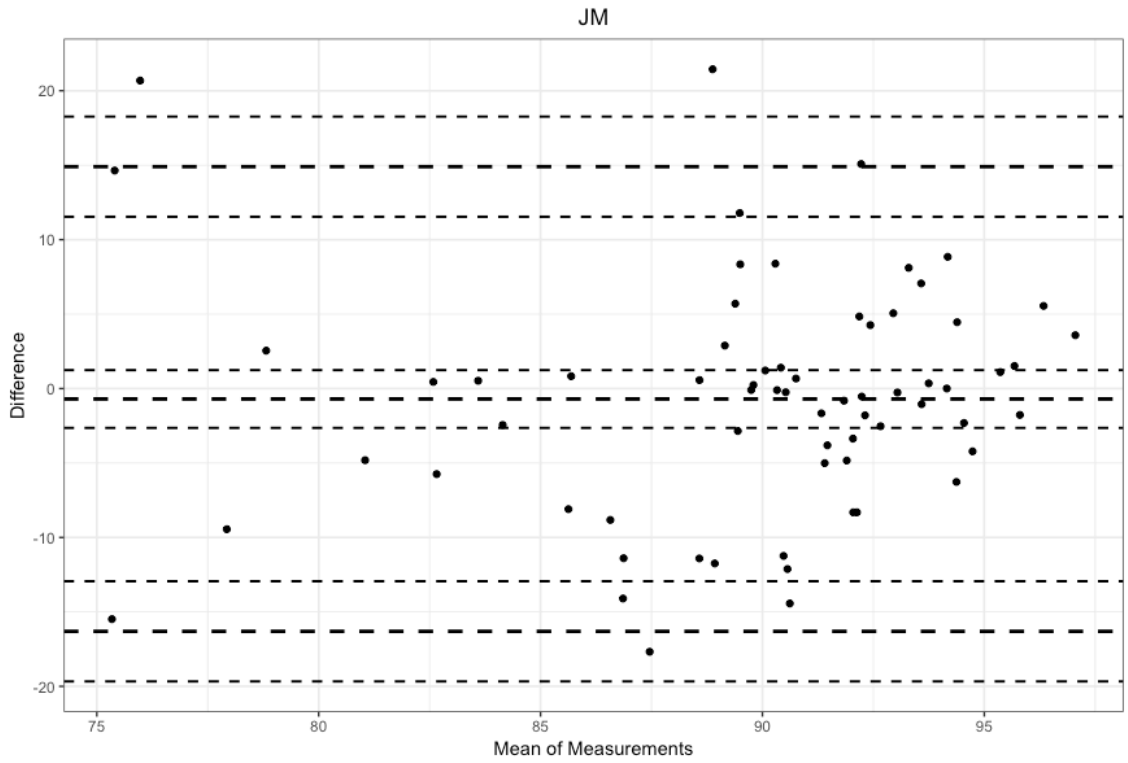

Figure 13: Bland-Altman plots for post-pre JM comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

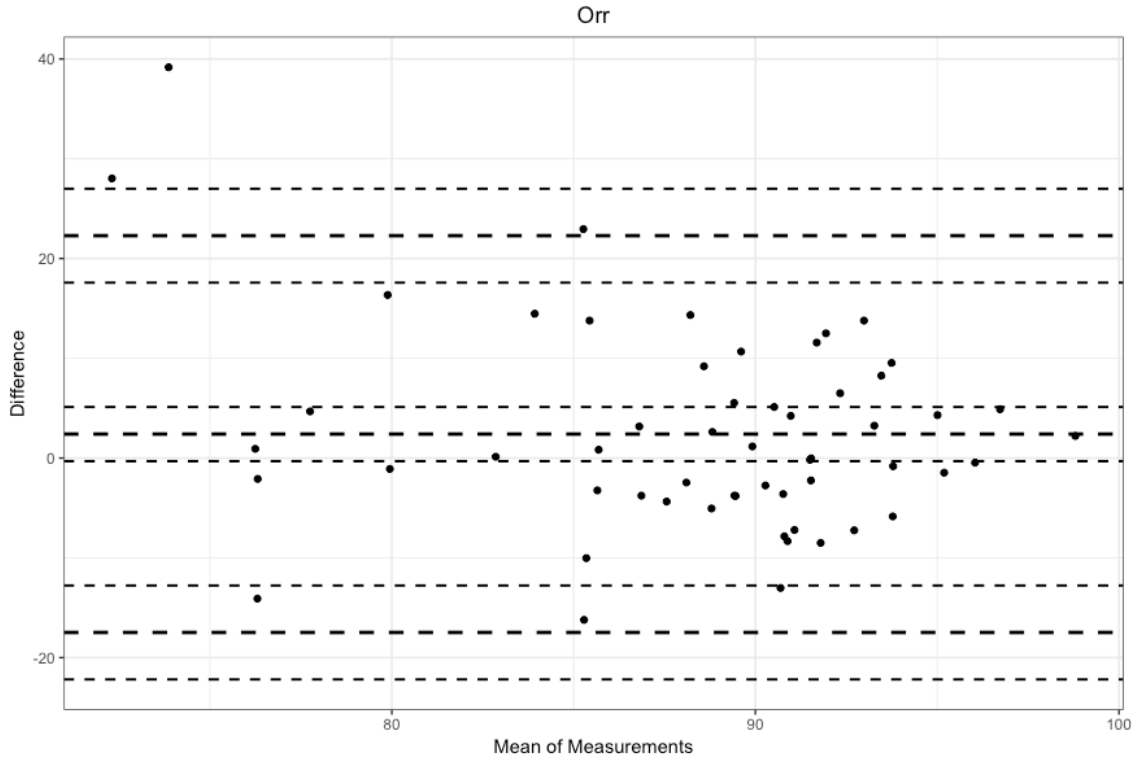

Figure 14: Bland-Altman plots for post-pre Orr comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

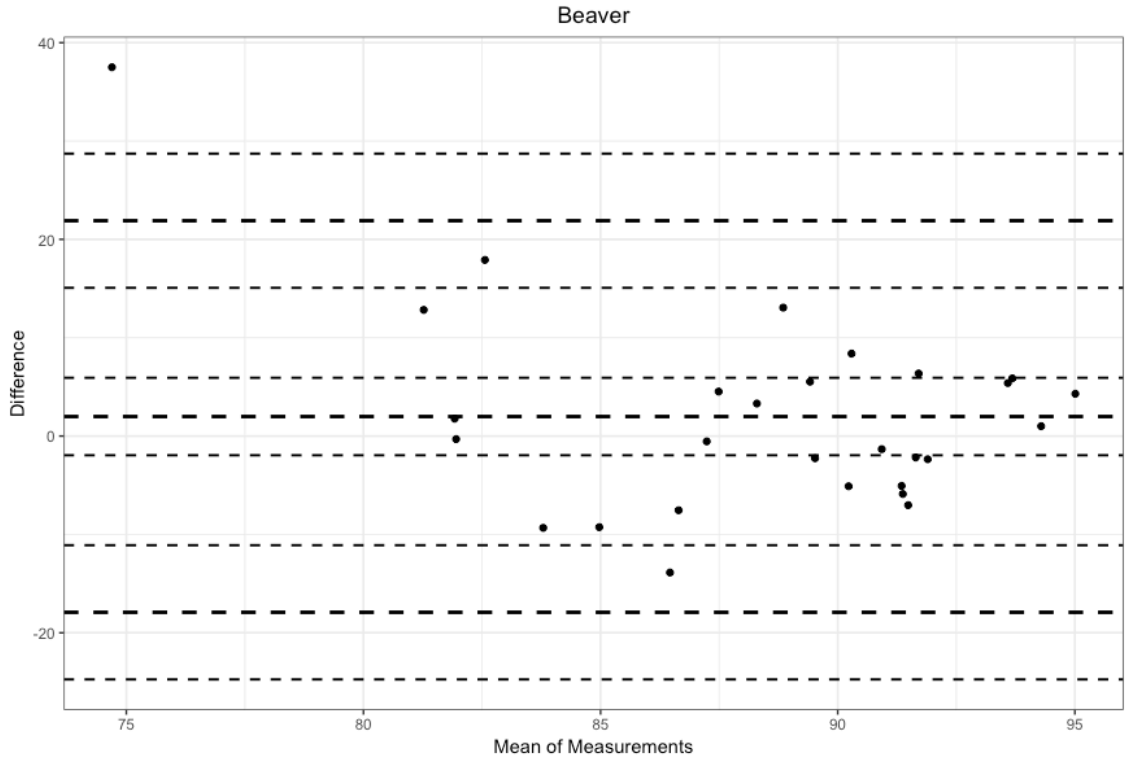

Figure 15: Bland-Altman plots for post-pre Beaver comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

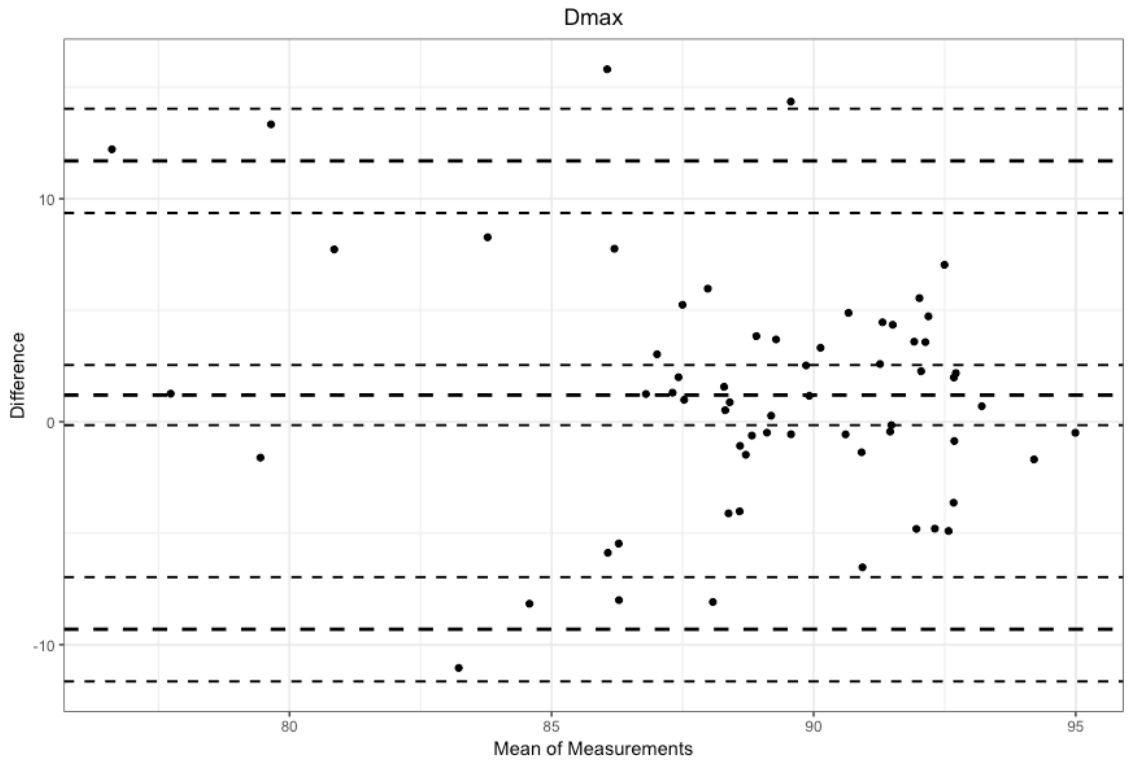

Figure 16: Bland-Altman plots for post-pre Dmax comparison. Wide dashed lines (–) represent the estimated mean difference as well as upper and lower LOA. Narrow dashed lines (-) are 95% confidence intervals for means as well as upper and lower LOA.

Chapter 5: Discussion

5.1 Automated Method Detection Rates

This is one of the few studies to compare different methods when detecting RC. Of those that have compared the means from multiple methods (McLellan, 1985), only two have compared automated methods (Santos & Giannella-Neto, 2004; Zhou & Weston, 1997). In contrast to those and other studies focusing on VT_1, this study employed percentage-based criteria to determine if a given method found a "determinate" RC. In other studies, it is unknown to what extent the slope at the breakpoint increased or if a two-line breakpoint model reduced the mean square error from a single line regression. The 10% or greater increase in slope at the breakpoint and a reduction in mean square error by at least 10% were intended as quality control measures to ensure that the solution provided by each method truly indicated RC. Without such measures any given formula could find that the best breakpoint is a decrease instead of an increase in slope or an increase in slope so small it does not differ from a single regression model. Similar quality control may have been assessed visually by investigators in previous studies. There is currently no consensus regarding the increase in slope or decrease in mean square error necessary to determine if a breakpoint represents RC. To date only Beaver et al. (1986) has suggested a specific value of a 15% increase in the V_E vs. VCO_2 slope. Given the determination criteria in this study, it was not surprising that some tests would be marked as "indeterminate" by one or more methods.

This study had a lower determinate rate than previous studies. However, it has been reported that similar automated methods fail to find VT_1 in as many as 30% of cases (Cheng et al., 1992). Furthermore, not all subjects present respiratory compensation (Beaver et al., 1986); this can occur in up to ⅓ of participants (Ekkekakis et al., 2008). In this study, all but the Beaver method had similar or higher rates of indetermination at pre testing than 33% (Table 1). However, this was different at post testing where the smallest indeterminate rate was 37.4%. This could signify a potential training effect that results in less dramatic, if any, hyperventilation. The form of this training effect may be due to increased entrainment (Bernasconi, Bürki, Bührer, Koller, & Kohl, 1995).

In this context, entrainment is coordinated respiration and locomotion to improve efficiency. Although entrainment was not measured in this study, it is theorized as the possible reason for higher indeterminate RC post training. Entrainment is usually more obvious with greater upper body involvement, such as in cross country skiing, rowing, and wheel chair propulsion (Fabre et al., 2012), but entrainment also occurs during running in both animals and humans alike (Bramble & Carrier, 1983). Humans are notable compared to other mammals in that their bipedal locomotion allows for a wide variety of stride to breath ratios: nearly all mammals are quadrupeds and use a 1:1 stride to breath ratio almost exclusively; humans in contrast can transition from as slow as 4:1 to as fast as 1:1 as intensity increases (Bramble & Carrier, 1983). Therefore, ventilation while running is coordinated with but is not fixed during human locomotion. A flexible stride to breath ratio then better permits central and peripheral chemoreceptors, especially at higher exercise intensities (Ward, 1994), to override locomotor control of breathing. In comparison to running, the more tightly fixed entrainment from the upper body involvement in cross country skiing makes RC more difficult to detect in that sport (Fabre et al., 2012).

Another notable aspect of entrainment is that its control over breathing mechanics appears to change with increased aerobic fitness. Aerobically trained runners are better able to coordinate breathing and stride frequency at higher intensities than untrained or sprint trained runners (Bernasconi et al., 1995). Although absolute and relative VO_{2max} was not significantly different pre to post training in this study, average 2-mile times were significantly faster after training, thereby indicating better aerobic fitness. Hence, the general trend across all methods that fewer participants had a determinate RC at post testing could be due to more efficient entrainment at higher exercise intensities. This could account for reduced hyperventilatory responses that made it difficult to determine RC post training.

Finally, this is the first study to examine determination rates between methods by employing a bootstrap resampling or similar technique. By plotting the results as overlapping histograms (Figure 3), we are provided with visual information that the JM, Orr, and Dmax methods have little to no overlap with Beaver's V-slope method. Although this is not a statistical test, it is nevertheless informative regarding which

methods have similar and different detection rates. Beaver's V-slope method was also the only method with a non-significant Fisher's exact test. This and the histogram plots suggest that the JM, Orr, and Dmax methods may be superior to Beaver's V-slope based on higher detection rates.

This study also appears to be the first to assess RC both before and after an endurance training program and to assess how this affects RC determination. The Fisher's exact tests suggest that some methods are more likely to find an individual as determinate at both timepoints. All but the Beaver method had significant odds ratios different from zero. This suggests that if the JM, Orr, or Dmax method classifies someone's RC as determinate before a training program, it has a higher propensity to find a determinate RC after that training program. Although this study didn't find an average difference pre to post training regarding the $\%VO_{2max}$ at RC, the results from the Fisher's exact tests suggest that the JM, Orr, and Dmax methods may be superior to Beaver's V-slope in that they are more likely to track changes by providing determinate values to compare from both timepoints.

5.2 Comparison of Automated Methods

The other notable finding from this study was the significantly higher $\%VO_{2max}$ at RC for the JM method compared to Beaver's V-slope or Dmax, but not compared to Orr. To our knowledge, this is the first study to report a systematic difference of one breakpoint method regarding the V_E vs. VCO_2 slope. In practice, these differences are small: the mean $\%VO_{2max}$ for Beaver's V-slope and Dmax is 0.97% and 0.93% lower, respectively. A difference this small may be too difficult to easily provide coaches or athletes with better information to change training. That aside, the RC represents the limit between sustainable and unsustainable exercise; overshooting by even a small margin can result in a downward spiral of fatigue. Despite this small difference, it is unknown if JM overestimates or if the others underestimate the $\%VO_{2max}$ at RC. This study did not perform confirmation tests where participants would run at the $\%VO_{2max}$ predicted by each method. Such a test could be similar to that of a MLSS test involving 30 minutes of running. If participants reached exhaustion or displayed hyperventilation during the test, it would suggest an overestimation of RC.

It was somewhat surprising that there was no difference between pre and post $\%VO_{2max}$ at RC. A training effect was expected that would increase the $\%VO_{2max}$ at RC. However, it's possible that many participants were already near their upper limit for RC when expressed as a $\%VO_{2max}$. However, that does not suggest that participants did not increase their fitness at this intensity. As noted by Coyle (2007), training can improve speed at this intensity, even if the $\%VO_{2max}$ does not increase. Given the drops in 2-mile performance pre to post training, participants likely increased their economy and could move at a faster pace at this intensity.

It was also somewhat unexpected that the correlations between the $\%VO_{2max}$ for a given method with 2-mile performance was weak at pre testing or non-significant for any method at post testing. Given that a higher $\%VO_{2max}$ at RC generally indicates better endurance capabilities, one might expect a stronger and significant negative correlation at both timepoints. When comparing pre to post 2-mile performance, the standard deviation was smaller at post testing for males, females, and for both sexes combined (Table 1). It is possible then that the $\%VO_{2max}$ at RC correlates significantly with performance when there is wider variation in the fitness, such as at pre testing.

Despite the strong and significant correlations between methods at both pre and post testing, the Bland-Altman plots revealed generally wide agreement. There is not a standard definition for what constitutes wide or narrow agreement because it depends on context. However, we consider an average LOA between methods of 15.69 and between timepoints for the same method of 32.95 as wide (Table 6). Regarding agreement between different methods, this can be considered wide because training at two work1oads 15% VO_{2max} apart could result in different training adaptations. The higher workload would likely produce more anaerobic adaptations whereas the lower workload would produce more aerobic adaptations. The even wider LOA for the same method between timepoints may represent large variability in when subjects display RC. Given that RC is multifaceted, this is not entirely surprising. The wide LOA could also represent the variability of how training affects RC.

Despite the wide LOA's, agreement between methods was generally better when considering values ranging from roughly 80-95% VO_{2max}. This parallels the heterogeneity of variance and linearity results seen in figure 4. Those results suggest that comparisons

between methods should be considered only when both are within the ranges of 80-95% VO_{2max}. The Bland-Altman plots also revealed that all methods had a consistent upward trend when compared to the Dmax method. Thus, when compared with Dmax, all methods generally predicted lower values when the mean between methods was below 90% VO_{2max}. Above a mean of 90% VO_{2max}, all other methods generally predicted higher than Dmax.

The clustering of values around 80-95% VO_{2max} likely represents that most individuals' RC in this study was near the upper limit of RC. This likely contributes to the heterogeneity of variance of RC because a low RC value has a greater range of possible values than high RC when expressed as a $\%VO_{2max}$. In general, the RC model from this study should be used with caution for values different from the 80-95 $\%VO_{2max}$ range due to heterogeneity of variance outside this window. With that in mind, if the Bland-Altman plots are reassessed visually with the range of 80-95%, the comparisons between different methods are better: the LOA appears closer to 10 or less. That aside, a difference of ± 5% VO_{2max} is large enough to over or underestimate RC. In practice, this could result in training that quickly become too hard or those that are not challenging enough.

Another difference in comparison to other studies is the use of a LMEM rather than an ANOVA or a related MANOVA. The choice to use a LMEM was based on the limitation of a MANOVA requiring complete data in all conditions. The quality control measures resulted in most participants being marked as indeterminate by one or more methods and at one or more timepoints. The consequence of performing a broad comparison of all methods and at both timepoints thus diminished the original 131 participants to 12, even after multiple transformations. When using a LMEM, only subjects who were marked as indeterminate by all four methods at one or both timepoints were excluded. This resulted in a considerably higher sample of 89, thus broadening the statistical power and generalizability of the findings.

A limitation of this study was the non-traditional graded exercise test. The effect of this test was that the data included for RC determination began at a higher $\%VO_{2max}$. In theory this is not ideal because lower values of V_E, VO_2, and VCO_2 provide more data points to find the best two-line regression. In essence, breakpoints may have been less

apparent given this study design. However, if a subject underwent respiratory compensation before the last minute of the 6-minute steady state period, the determination criteria would have marked them as indeterminate as no change would likely be present. Despite that, it is unlikely that subjects surpassed RC in the midst of the 6-minute steady-state period as this speed was closer to a marathon pace. That is, most individuals could likely continue this pace for a long duration, thereby suggesting they were beneath their upper sustainable limit of exercise intensity. In addition, this pace was closer to VT_1 at 67.9 and 70.9% VO_{2max} at pre and post testing, respectively. Also, other studies have reported values of RC from 75.5 – 91% VO_{2max} depending on the visual or automated method used (McLellan, 1985; Santos & Giannella-Neto, 2004; Zhou & Weston, 1997). The average RC across all timepoints and methods was 88.9% in this study. Taken together, few participants likely surpassed RC during the steady state period because the average $\%VO_{2max}$ during the steady state was lower than the average RC in this and most other studies. Those that may have surpassed RC during the middle of the steady state were likely excluded from LMEM analysis due to the determination criteria.

Given the possibility that some individuals may have undergone RC during the steady state, this may have affected how often a given method denoted that participant's RC was indeterminate. Therefore, the number of indeterminate cases in this study may have been somewhat elevated. Given that, it would be helpful to compare these results to future studies with more traditional graded exercise tests.

Despite that potential limitation, this study found several important results. First, it found that Beaver's V-slope had consistently lower determination rates than the others, suggesting the JM, Orr, and Dmax should be used when assessing RC using the V_E vs. VCO_2 relationship. In addition, this study found that the JM method gave significantly higher estimates the $\%VO_{2max}$ at RC than the Beaver and Dmax methods. Without confirmation methods, it is unknown if this is an overestimation. Also, this study found that the Dmax method has an upward trend when assessing agreement with other methods. Without confirmation tests where participants run at the $\%VO_{2max}$ predicted by a given method, it is unknown if this upward trend by the Dmax method results in under and overestimations of RC.

The results of this study do not make it possible to declare a given method as superior over the others, but this analysis does suggest that Beaver's V-slope may be inferior given its low determination rate. In addition, the Dmax method may also be inferior given its trending agreement when compared to other methods. The JM method, too, raises questions given that it gave higher RC estimates than the Dmax and Beaver methods. Lastly, this study only examined one graphical relationship used to assess RC: the V_E vs. VCO_2 curve. It is possible that results would be different if these methods were applied to other relationships such as the V_E/VCO_2 or $P_{ET}CO_2$ vs. VO_2 or time. Results could also differ when applied to other fitness levels and ages besides recreationally active college students. Like the results from the VT_1 study by Gaskill et al. (2001), a combination of methods and assessments with different graphical relationships may improve both determination rates, reduce variance, and improve agreement to other measures of the second threshold.

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Chapter 7: Appendix

7.1: Consent Form and IRB Number:

IRB Code # 1507E76784, version date: 11/25/2015

Physiological Adaptation to Marathon Training Consent Form

You are invited to participate in a research study of physiological response to marathon training. You were selected as a possible participant because you are enrolled in PE 1262 Marathon Training. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by Christopher Lundstrom, Ph.D., from the University of Minnesota School of Kinesiology.

Study Purpose

The purpose of the study is to examine physiological response to marathon training in recreational runners, as well as to assess relationships between physiological, metabolic, and training variables and running outcomes.

Study Procedures

If you agree to participate in this study, you are agreeing to allow the use of data collected as part of PE 1262 Marathon Training to be used for research purposes. Specifically, your pre-course questionnaire, time trials, marathon run, training log data, metabolic (VO_{2MAX} testing), body composition testing, and anthropomorphic measures may be used.

Risks of Study Participation

The study has the following risks. Marathon training and treadmill VO_{2MAX} testing involve a high level of physical exertion. This may represent a change from normal physical activity levels and may result in injury or in extremely rare cases, death.

Benefits of Study Participation

There are no benefits to study participation outside of that which may be expected from the educational and possible physical benefits from participation in the class.

Alternatives to Study Participation

You may participate in PE 1262 without allowing your data to be used for research purposes.

Study Costs/Compensation

You will not incur any costs or receive any compensation as a result of participation in this study.

Research Related Injury

In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Care for such injuries will be billed in the ordinary manner to you or your insurance company. If you think that you have suffered a research related injury, let the study staff know right away.

Confidentiality

The records of this study will be kept private. In any publications or presentations, we will not include any information that will make it possible to identify you as a subject. Your record for the study may, however, be reviewed by departments at the University with appropriate regulatory oversight. Study information will not be recorded in your medical record. Data will be coded by study participant number and identifying information will be removed prior to use for research purposes. Transmission of data via the internet will be done only after de-identification. To these extents, confidentiality is not absolute. Study data will be encrypted according to current University policy for protection of confidentiality.

Voluntary Nature of the Study

Participation in this study is voluntary. Your decision whether or not to participate in this study will not affect your current or future relations with the University of Minnesota or the School of Kinesiology. If you decide to participate, you are free to withdraw at any time without affecting those relationships.

Contacts and Questions

The researcher conducting this study is Christopher Lundstrom, Ph.D. You may ask any questions you have now, or if you have questions later, **you are encouraged to** contact him at 612-381-7970.

If you have any questions or concerns regarding the study and would like to talk to someone other than the researcher(s), you are encouraged to contact the Fairview Research Helpline at telephone number 612-672-7692 or toll free at 866-508-6961. You may also contact this office in writing or in person at *Fairview Research Administration, 2344 Energy Park Drive, St. Paul, MN 55108.*

You will be given a copy of this form to keep for your records.

Statement of Consent

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature of Subject_____

Date_____

Signature of Person Obtaining Consent_____

Date_____

7.2: Participant Testing Instructions

UNIVERSITY OF MINNESOTA

Dear Marathon Class Runner,

Your lab testing time is coming up shortly. Please be prompt and prepare for this test as indicated below. Please plan on this appointment lasting between 1 hour and 1 hour and 30 minutes. Testing will be done in the Laboratory of Physiological Hygiene (UREC 27), located in the basement of the University Rec. Center, near the Equipment Room desk in the North Building. It is on your left as you enter the tunnel to go toward the fieldhouse.

In order to ensure the utmost in accuracy we ask that you comply with the following:

Pre-Test Instructions:

Be sure that you are rested. If you exercise the day before the test, be sure it is of light to moderate intensity a relatively short duration. You should not exercise within 12 hours of your test. You should not have eaten within 3-4 hours of the test. Avoid alcohol, caffeine, and tobacco within 8 hours of the test.

Be sure you are adequately hydrated. Drink adequate amount of water during the hours before the test.

Tests Completed (required for class, however you may choose to not have your data as a part of research if you desire)

- Consent form (optional, allows data to be used for research)
- History and information questionnaire
- Body Composition (underwater weighing: height, weight, and immersed weight)
- Vertical jump
- Graded Exercise Test: VO_2max running test on treadmill

Clothing to bring with you for your testing:

-Running shoes
-Swim suit or compression-type garments
-Towel
-Running shorts
-Running top

Additional Preparation and Instructions:

Upon your arrival, you will be given a medical history questionnaire and a consent form. Please be sure to have all necessary information available such any pertinent medical information.

If you must cancel or reschedule your test, please do so at least 48 hours in advance. (contact Chris Lundstrom, lund0982@umn.edu, 612-381-7970)

7.3: Winter Break Training Schedule: Novice

PE 1262: Marathon Training - Winter Break Training Plan 2016-17: Novice									
WEEK	DATE (MON)	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL
1	12/5/16	10 min.	OFF	15 min.	OFF	15 min.	OFF	25 min.	65 min
2	12/12/16	10 min.	OFF	20 min.	OFF	20 min.	OFF	30 min.	80 min.
3	12/19/16	OFF	25 min.	15 min.	OFF	20 min.	35 min.	OFF	95 min
4	12/26/16	15 min.	OFF	30 min.	OFF	20 min.	40 min.	OFF	105 min.
5	1/2/17	20 min.	OFF	30 min.	OFF	20 min.	OFF	50 min.	120 min.
6	1/9/17	OFF	20 min.	30 min.	OFF	20 min.	OFF	6-mile run (60 min)	130 min.
7	1/16/17	OFF	20 min.	First day of class!!! Meet in Fieldhouse for 2-mile TT					

7.4: Winter Break Training Schedule: Intermediate

PE 1262: Marathon Training - Winter Break Training Plan 2016-17: Intermediate									
WEEK	DATE (MON)	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL
1	12/5/16	15 min.	OFF	25 min.	OFF	20 min.	OFF	30 min.	90 min.
2	12/12/16	20 min.	OFF	15 min.	20 min.	15 min.	OFF	35 min	105 min.
3	12/19/16	OFF	30 min	25 min.	OFF	25 min	40 min.	20 min	115 min.
4	12/26/16	OFF	20 min.	30 min.	OFF	30 min.	50 min.	OFF	130 min.
5	1/2/17	20 min.	OFF	30 min	20 min.	OFF	15 min.	60 min.	145 min.
6	1/9/17	OFF	20 min.	35 min.	20 min.	OFF	15 min.	7-mile run (70 min)	160 min.
7	1/16/17	OFF	20 min.	First day of class!!! Meet in Fieldhouse for 2-mile TT					

7.5: Winter Break Training Schedule: Advanced

PE 1262: Marathon Training - Winter Break Training Plan 2016-17: Advanced									
WEEK	DATE (MON)	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL
1	12/5/16	20 min.	OFF	25 min.	20 min.	OFF	15 min.	40 min.	120 min.
2	12/12/16	OFF	20 min	25 min.	20 min.	OFF	20 min	45 min	130 min.
3	12/19/16	OFF	35 min	30 min	OFF	30 min	50 min.	OFF	145 min.
4	12/26/16	35 min.	OFF	35 min.	OFF	35 min.	60 min.	OFF	165 min.
5	1/2/17	40 min	OFF	20 min.	35 min.	OFF	20 min.	70 min.	185 min.
6	1/9/17	OFF	30 min.	40 min.	30 min.	OFF	20 min.	8-9 mile run (80 min)	200 min.
7	1/16/17	OFF	30 min.	First day of class!!! Meet in Fieldhouse for 2-mile TT					

7.6: Spring Semester Training Schedule

PE 1262: Marathon Training 2016-17 – Spring Semester Training Schedule							
WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
	1/16	1/17	1/18	1/19	1/20	1/21	1/22
1	OFF	20-30 min	First day of class!!! 2 mile TT	OFF	20-30 min	OFF, or 20 min run	8 miles
	1/23	1/24	1/25	1/26	1/27	1/28	1/29
2	OFF	30 min	30 min run w/ drills + accels	OFF	30-40 min	OFF, or 20 min run	10 miles
	1/30	1/31	2/1	2/2	2/3	2/4	2/5
3	OFF	30 min	20 min AT (+warm/cool)	OFF	30-40 min	OFF, or 20 min run	90 min on own
	2/6	2/7	2/8	2/9	2/10	2/11	2/12
4	OFF	30-40 min	30-40 min w/ hills	OFF	30-40 min	OFF, or 20 min run	12 mile
	2/13	2/14	2/15	2/16	2/17	2/18	2/19
5	OFF	30-45 min	10, 10, 5 min AT w/ 2 min rec.	OFF	30-40 min	OFF, or 20 min run	14 miles
	2/20	2/21	2/22	2/23	2/24	2/25	2/26
6	OFF	30-40 min	Fartlek	OFF	30-40 min	OFF, or 20 min run	90 min on own
	2/27	2/28	3/1	3/2	3/3	3/4	3/5
7	OFF	30-40 min	6x5 min AT w/ 1 min rec.	OFF	30-40 min	OFF, or 20 min run	**U of MN Half Marathon**
	3/6	3/7	3/8	3/9	3/10	3/11	3/12
8	OFF	30-40 min	Hills	OFF	40-50 min	Spring Break OFF	90 min. on own
	3/13	3/14	3/15	3/16	3/17	3/18	3/19
9	OFF	30-45 min	40 min w/ 20 min AT	OFF	30-40 min	OFF, or 20 min run	15 miles on own
	3/20	3/21	3/22	3/23	3/24	3/25	3/26
10	OFF	30-50 min	3x10 min AT	30 min	30-40 min	OFF or 20 min run	18 miles
	3/27	3/28	3/29	3/30	3/31	4/1	4/2
11	20-30 min	30-45 min	30 min fartlek	OFF	30-40 min	OFF, or 20 min run	90 min on own
	4/3	4/4	4/5	4/6	4/7	4/8	4/9
12	OFF	30-40 min	2 mile TT	OFF	30-40 min	OFF, or 20 min run	20 miles
	4/10	4/11	4/12	4/13	4/14	4/15	4/16
13	OFF	30-40 min	6x3 min on/2 min off	OFF	30-40 min	OFF, or 20 min run	2:00 on own
	4/17	4/18	4/19	4/20	4/21	4/22	4/23
14	OFF	30-40 min	2x15 min AT	OFF	30 min	OFF, or 20 min run	70-80 min.
	4/24	4/25	4/26	4/27	4/28	4/29	4/30
15	OFF	20-30 min	20-30 min w/ 5 min pickup	OFF	10 min run	**Marathon**	OFF